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EXPLORING THE NATURE OF THE LINKS BETWEEN MOTOR AND LANGUAGE DEVELOPMENT IN INFANCY

S.S.D. M-PSI/04 - PSICOLOGIA DELLO SVILUPPO E DELL'EDUCAZIONE

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SUMMARY (Italian)

Introduzione

Lo sviluppo motorio e lo sviluppo linguistico sono stati storicamente considerati come domini separati e indipendenti da diverse prospettive teoriche. Solo negli ultimi decenni, la psicologia ecologica e la teoria dei sistemi dinamici di sviluppo hanno spinto molti ricercatori a studiare il co-sviluppo delle abilità motorie e delle abilità linguistiche, esplorando le possibili relazioni tra i due domini di sviluppo, in particolare gli effetti a cascata che si possono generare dall'acquisizione di importanti abilità motorie (quali, ad esempio la locomozione autonoma) sull'apprendimento del linguaggio. I risultati hanno dimostrato che questi due domini sono molto più connessi di quanto si pensasse sia in bambini con sviluppo tipico che atipico. Inoltre, la prospettiva dell'*embodied cognition*, evidenzia come la cognizione (incluso il linguaggio) si sviluppi attraverso processi di percezione-azione. Quando i bambini esplorano fisicamente l'ambiente, è attraverso il loro corpo e i movimenti e le azioni che sono in grado di fare che imparano a conoscere le possibilità che l'ambiente offre loro, raccogliendo informazioni su spazio, persone e oggetti. Queste "percezioni-azioni" supportano lo sviluppo della cognizione e possono altresì sostenere l'acquisizione del linguaggio, ad esempio, facilitando l'abbinamento tra il referente (esperito direttamente) e l'etichetta verbale, che viene inizialmente offerta dai genitori per poi diventare parte del vocabolario del bambino. Ma quali abilità motorie risultano essere cruciali nell'attivare processi più funzionali al co-sviluppo del movimento e del linguaggio? Sebbene numerosi, recenti studi sia trasversali che longitudinali abbiano già indagato diversi aspetti della relazione tra sviluppo motorio e sviluppo del linguaggio, non è ancora chiaro se alcune abilità motorie specifiche siano più associate di altre alle abilità linguistiche (come competenza complessiva) o a specifiche abilità linguistiche, e quali meccanismi sottendano la relazione tra acquisizioni motorie e acquisizioni linguistiche.

Obiettivi

L'obiettivo principale del progetto di ricerca è quello di approfondire la relazione

tra sviluppo motorio e sviluppo linguistico nei primi tre anni di vita, esplorando i possibili legami tra specifiche abilità motorie ad oggi solo marginalmente studiate e specifiche abilità linguistiche. In particolare, sono tre gli obiettivi specifici che si pone: (1) sintetizzare e analizzare la letteratura di riferimento per individuare possibili traiettorie di sviluppo del linguaggio innescate da specifiche competenze motorie, già evidenziate in studi precedenti; (2) approfondire il potenziale contributo delle prime forme di locomozione autonoma allo sviluppo linguistico del bambino nei primi 16 mesi di vita, tenendo in considerazione anche altri fattori, sia individuali (il livello di competenza comunicativa e il genere del bambino) che sociali (le caratteristiche del linguaggio dei genitori diretto al bambino), che è stato dimostrato abbiano un ruolo fondamentale nello sviluppo del linguaggio. Particolare attenzione viene riservata alla prima forma di locomozione autonoma, il gattonamento, indagata marginalmente rispetto al cammino; (3) esplorare il potenziale contributo di alcune capacità coordinative (sia fino- che grosso-motorie) allo sviluppo linguistico del bambino nel periodo a cavallo tra il secondo e terzo anno di vita, considerando anche specifiche abilità linguistiche che possono essere più facilmente associate alle azioni (la comprensione e produzione di predicati) e alle esperienze motorie (il vocabolario spaziale).

Metodo

Per perseguire il primo obiettivo è stata realizzata una revisione sistematica della letteratura, utilizzando tre banche dati (*PsycInfo*, *PubMed* e *Web of Science*) e applicando specifici criteri di inclusione ed esclusione per selezionare i record identificati.

Per perseguire il secondo obiettivo sono stati realizzati due studi. Nello Studio 1 sono stati coinvolti 59 famiglie italiane. A 8, 12 e 16 mesi di età del bambino, i genitori hanno compilato: (1) un questionario per valutare lo sviluppo motorio del bambino (la sezione dell'*Early Motor Questionnaire* dedicata allo sviluppo grosso-motorio; dagli item del questionario abbiamo definito due misure motorie: la *performance* di gattonamento a 8 mesi e quella di locomozione a 12 mesi; (2) un questionario per valutare lo sviluppo del linguaggio del bambino (*Il primo* *vocabolario del bambino - Gesti e parole*), di cui abbiamo considerato: il repertorio dei comportamenti comunicativi (a 8 e 12 mesi), il vocabolario ricettivo (a 12 e 16 mesi) e il vocabolario produttivo (a 16 mesi). Per la realizzazione dello Studio 2 è stato coinvolto un sottogruppo del campione dello Studio 1 (N = 31). Partendo dalle date di avvio del gattonamento e del cammino (di cui era stato chiesto ai genitori di tenere traccia) è stata definita la competenza deambulatoria dei bambini a 8 mesi (chi gattonava vs chi non gattonava), 12 mesi (chi camminava vs chi gattonava) e 16 mesi (chi aveva un'esperienza di cammino maggiore vs minore di tre mesi). A 8, 12 e 16 mesi di vita del bambino l'interazione genitore(i)-bambino è stata videoregistrata durante una sessione di gioco libero. Gli input verbali dei genitori durante i primi cinque minuti di attività di gioco ininterrotta sono stati prima trascritti per ottenere misure delle caratteristiche strutturali del linguaggio e successivamente codificati secondo sei categorie di funzioni comunicative: (1) direttive; (2) richieste di azioni; (3) richieste verbali; (4) *scaffolding* linguistico; (5) *feedback* positivi; (6) affermazioni.

Per perseguire il terzo obiettivo sono stati coinvolti 36 bambini, divisi in due gruppi in base all'età al momento della prima valutazione: un gruppo di 18 mesi (N = 18) e un gruppo di 24 mesi (N = 18). Entrambi i gruppi sono stati valutati due volte (T1 e T2), a sei mesi di distanza. Al T1, sia le abilità motorie che quelle linguistiche sono state misurate utilizzando le *Griffiths Mental Development Scales* (GMDS). Per poter misurare le capacità coordinative, gli *items* delle scale A (Locomotoria) e D (Coordinazione oculo-manuale) sono stati organizzati in quattro categorie di coordinazione grosso-motoria: coordinazione dinamica generale, equilibrio, organizzazione spaziale e coordinazione oculo-motoria, e quattro categorie di coordinazione fine-motoria: manipolazione degli oggetti, destrezza fine della mano, coordinazione bilaterale e integrazione visuo-manuale. Al T2, sono state valutate solo le abilità linguistiche, utilizzando il PiNG (Parole in Gioco), uno strumento standardizzato che consente la valutazione della comprensione e della produzione di nomi e predicati separatamente. Infine, dagli item delle prove PiNG è stata estrapolata una misura di vocabolario spaziale, che comprende predicati, avverbi locativi e aggettivi.

Risultati

L'analisi sistematica della letteratura (Capitolo 2) ha identificato un totale di 24 articoli. Di questi, 13 hanno considerato solo specifiche abilità grosso-motorie: la posizione seduta, il gattonamento, la posizione eretta, il camminare e alcune capacità di coordinazione grosso-motoria; 5 studi hanno considerato solo specifiche abilità fino-motorie: presa e manipolazione, dominanza e alcune capacità di coordinazione fine-motoria; 6 studi hanno considerato sia abilità grosso- che fino-motorie. I risultati degli studi nel loro complesso hanno evidenziato tre potenziali traiettorie di sviluppo del linguaggio innescate da specifiche competenze motorie: il miglioramento del controllo posturale (controllo della testa, della posizione seduta e successivamente della posizione eretta), la conquista del cammino e l'esperienza di manipolazione fine, sebbene solo per il cammino le evidenze empiriche risultino sufficientemente robuste e coerenti.

I risultati del primo studio (Capitolo 3) evidenziano che l'avvio del gattonamento può contribuire allo sviluppo del linguaggio nel breve e medio termine. I bambini che a 8 mesi dimostrano una maggiore competenza nel gattonare risultano avere migliori abilità linguistiche alla stessa età e quattro mesi dopo. Inoltre, lo studio conferma, seppur parzialmente, i risultati di precedenti studi sul cammino, evidenziando che i bambini che a 12 mesi dimostrano una maggiore competenza nel camminare risultano avere un vocabolario recettivo più ricco a 16 mesi. Rispetto al legame tra competenza nella locomozione autonoma e input verbali offerti dai *caregivers*, i risultati evidenziano due aspetti: (1) la locomozione autonoma del bambino condiziona alcune funzioni linguistiche del linguaggio dei *caregivers*, soprattutto attorno agli 8 mesi quando il gattonamento prende avvio; nel dettaglio, l'utilizzo delle direttive volte a controllare e contenere il movimento dei bambini più competenti e l'utilizzo dei feedback positivi volti a stimolare e incoraggiare i bambini meno competenti; (2) la competenza di locomozione concorre con altri fattori individuali (genere a 8 mesi e competenza linguistica misurata quattro mesi prima) e sociali (richieste verbali e *scaffolding* linguistico dei *caregivers*) allo sviluppo linguistico del bambino; nel dettaglio, a 8 mesi l'avvio del gattonamento contribuisce con il genere e gli input verbali dei genitori (sia caratteristiche strutturali che funzionali) alla competenza linguistica del bambino misurata alla stessa età; a 12 mesi, l'avvio del cammino concorre con le abilità linguistiche del bambino e lo *scaffolding* linguistico dei genitori a predire il vocabolario recettivo a 16 mesi.

I risultati del secondo studio (Capitolo 4) evidenziano che le abilità motorie possono influenzare lo sviluppo linguistico anche nel periodo a cavallo tra il secondo e terzo anno di vita, ma il contributo varia in base al tipo di abilità motoria considerata (grossa o fine) e all'età dei bambini. A 18 mesi, l'indice di sviluppo motorio globale predice la produzione di predicati e la coordinazione dinamica generale (GDC) predice la produzione di nomi a 24 mesi. A 24 mesi, la GDC predice la produzione di predicati e un modello che combina la coordinazione bimanuale e la GDC predice la comprensione del vocabolario spaziale a 30 mesi.

Conclusione

Nel complesso, questi risultati approfondiscono la conoscenza e la comprensione delle relazioni tra sviluppo motorio e sviluppo linguistico, facendo luce sui legami tra specifiche abilità motorie e linguistiche in due periodi di transizione importanti (per lo sviluppo di entrambi i domini), ma scarsamente indagati in letteratura. Essi dimostrano che è fondamentale spostare l'attenzione da misure globali di sviluppo motorio a misure specifiche considerando sia *milestones* che capacità coordinative e, quando gli studi coinvolgono bambini più grandi, da misure linguistiche globali a categorie linguistiche specifiche.

SUMMARY (English)

Introduction

Motor development and language development have historically been considered separately and viewed from different theoretical perspectives as independent domains. Only in the last few decades have ecological and dynamic systems approaches to development brought many researchers to study the co-development of motor skills and linguistic abilities. This has involved exploring the possibility of cross-domain interactions, particularly cascading changes in language acquisition resulting from the onset of fundamental motor skills such as self-locomotion. It has been shown that these two domains are more interrelated than was previously believed, both in typically developing children and in children with developmental disorders. The embodied-cognition approach, moreover, has highlighted that cognition (including language) emerges as a result of perception-action processes.

As children interact physically with their environment, they use body and actions to learn about what that environment offers them, gathering information about space, people, and objects. These perception-action experiences support cognitive development and can also support language acquisition. One example is the facilitation of matching between word-references (directly experienced) and word-labels offered by caregivers and then learned by the child. But which motor skills are crucial in activating the processes more helpful for motor and language co-development? Several recent studies have investigated, both cross-sectionally and longitudinally, the relation between motor development and language development. But it is still unclear whether particular motor skills are more related than others to language abilities (both global and specific) and which mechanisms underlie the links between motor and language development.

Aims

The broad aim of the research projects comprising this work is to deepen our understanding of the relationship between motor development and language development in the first three years of age by investigating the potential links—until now marginally investigated—between specific motor skills and specific

language skills. The three specific, auxiliary aims are as follows: (1) to synthesize and analyze the literature in order to identify the main trajectories of language development triggered by specific motor skills, already highlighted in previous studies; (2) to deepen understanding of the potential role of self-locomotion in infants' language development from 8 to 16 months of age, accounting for other factors—individual (infant's communicative abilities and gender) and social (parents' verbal input)—that have been shown to be related to infants' language development. We focus on crawling as the first form of self-locomotion; it is less investigated than walking; (3) to explore the potential contribution of some motor coordination skills (both gross and fine) to language development from 18 to 30 months of age. We will also consider specific language categories more related to actions (such as predicates) and motor experiences (such as spatial vocabulary).

Method

To achieve the first specific aim, a systematic review of the literature was conducted, exploring three bibliographic databases (PsychInfo, PubMed, and Web of Science) and using specific inclusion and exclusion criteria to select the records.

To achieve the second specific aim, we conducted two studies.

In Study 1, 59 Italian families were recruited. At around 8, 12, and 16 months of infant's age, parents completed two questionnaires. The first was used to assess the infant's motor development (the gross motor section of the Early Motor Questionnaire - EMQ). From EQM items, we derived two motor measures: crawling performance at eight months and locomotion performance at around 12 months. The second questionnaire was used to assess the infant's language development (CDI-Gestures and Words), from which we extracted the child's repertoire of communicative behaviors (at 8 and 12 months), receptive vocabulary (at 12 and 16 months), and productive vocabulary (at 16 months).

In Study 2, a subset of the sample of Study 1 (N = 31) was involved. Parents were asked to track the onset of both crawling and walking, and we used their reports to define the infants' locomotor status at eight months (crawlers vs. non-crawlers), 12 months (walkers vs. crawlers), and 16 months (walkers with ± three months of walking experience). At the same observation points, infant-parent(s) interaction was videotaped during a naturalistic play session. Parents' verbal input during the first five minutes of uninterrupted play activities was first transcripted to derive measures of language structural characteristics and then coded according to six categories of communicative functions: directives, action requests, verbal requests, linguistic scaffolding, positive feedback, and affirmations.

To achieve the third specific aim, 36 children were involved in a study. They were divided into two groups based on their age at the time of the first assessment: one of 18-month-old children (N = 18) and one of 24-month-old children (N = 18). Both groups of children were assessed twice, six months apart. At Time 1, motor and language skills were measured using the Griffiths Mental Development Scales (GMDS). In order to measure motor coordination skills, items from scales A (Locomotor) and D (Eye and hand coordination) were used. They were organized into four categories of gross-motor coordination skills— General dynamic coordination, Balance, Spatial organization, and Visual-motor coordination—and four categories of fine-motor coordination skills: Object handling, Manual dexterity, Bilateral coordination, and Visual-manual integration. At Time 2, only language outcomes were assessed, by using the Picture Naming Game (PiNG*)*, a standardized task that allows the assessment of noun and predicate comprehension/production separately. Finally, a spatial vocabulary was identified from the PiNG, including predicates of motor actions, locative adverbs, and adjectives.

Results

The systematic literature search (Chapter 1) identified 24 papers. Of these, 13 studies measured only specific gross motor skills: sitting, crawling, standing, walking, and gross motor coordination. Five studies measured only fine motor skills—grasping and manipulation, fine motor coordination skills, and handedness—and six studies measured both gross and fine motor skills. The reviewed studies suggest three potential developmental trajectories in the development of language abilities triggered by specific motor skills: improvement in postural control (head control, sitting, and standing), the attainment of walking,

and advanced manipulation experience. Consistent evidence, however, was found only for the link between the attainment of walking and language acquisition.
The results of the first study (Chapter 2) show that the onset of crawling may contribute to language development in the short to medium term. Infants with a high performance in crawling at eight months had better language abilities at the same age and four months later. These results also confirmed, although partially, previous findings focused on walking that showed that infants with a high performance in walking at 12 months had a richer receptive vocabulary four months later. We found two main results regarding the links between locomotor status and parents' verbal input. The first was that the infant's locomotor status shaped some functions of parents' verbal input, especially at eight months when the self-locomotion starts. Specifically, it shaped the use of directives aimed at controlling motor explorations of the more competent infants (who had already started crawling) and the use of positive feedback aimed at encouraging the less competent infants (who had not yet started self-locomotion). The second was that locomotor status contributed, along with other factors—individual (gender and language abilities four months earlier) and social (parents' verbal requests and language scaffolding)—to the infant's language development. Specifically, firstly, at eight months the onset of crawling concurred with gender and the parent's verbal input (both structural and functional characteristics) with the infant's language ability measured at the same age. And secondly, the onset of walking, accounting for the infant's language abilities and parents' linguistic scaffolding measured at 12 months, predicted receptive vocabulary at 16 months.
The results of the second study (Chapter 3) show that motor skills affect language abilities both in the late second and in the third year, but the impact varies according to the type of motor skills (gross *versus* fine) and children's age. At 18 months, a global score of gross motor skills predicted predicate production, and a specific gross-motor coordination skill (general dynamic coordination (GDC)) predicted noun production at 24 months. At 24 months, GDC predicted predicate production, and a combination of fine and gross motor coordination skills (bilateral coordination and GDC) predicted spatial vocabulary comprehension at 30 months.

Conclusion

Taken together, these results deepen our understanding of the relationship between motor and language development. They shed light on the links between specific motor skills and specific language skills during two transition periods that are crucial for both motor and language development. These links have received little attention so far. It is essential to shift the attention from global to specific motor scores (milestones and motor coordinative skills) and, when the investigation involves older children, from global to specific language categories.

INTRODUZIONE

Per decenni il movimento, il suo sviluppo e i meccanismi che lo regolano hanno ricevuto un'attenzione estremamente limitata all'interno della più ampia riflessione psicologica, tanto da essere considerati una sorta di "Cenerentola della psicologia" (Rosenbaum, 2005). Fortunatamente, negli ultimi decenni, alcuni approcci teorici hanno riacceso l'interesse sul movimento, non considerandolo più dominio autonomo e indipendente come in passato, ma strettamente interconnesso a tutti gli altri domini di sviluppo. Tra questi approcci, meritano di essere citati per l'apporto che hanno offerto a questo progetto di ricerca, l'*embodied cognition*, che sta offrendo solide evidenze scientifiche a sostegno del legame mente-corpo (Shapiro, 2011; Smith & Gasser, 2005) e la teoria dei sistemi dinamici di sviluppo (Kelso et al., 1980; Thelen, Kelso, & Fogel, 1987; Thelen & Fogel, 1988; Thelen & Smith, 1993) che ha rimesso lo sviluppo motorio al centro della riflessione psicologica inerente lo sviluppo del bambino, spingendo molti ricercatori a studiare il co-sviluppo delle abilità motorie e delle abilità proprie di altri domini.

Soprattutto quest'ultima prospettiva ha offerto alcune sollecitazioni risultate poi fondamentali per l'ideazione e successiva strutturazione di questo progetto di ricerca che punta ad approfondire le relazioni tra sviluppo motorio e linguistico nei primi tre anni di vita del bambino assumendo la specificità di tale relazione (se e come specifiche competenze motorie sono in relazione con specifiche abilità linguistiche) e analizzandola assieme ad altri fattori, sia individuali che sociali, che la possano influenzare.

Le principali prospettive teoriche di riferimento

L'*embodied Cognition*

L'idea di fondo che sottende la dicitura *Embodied Cognition* è che la gran parte dei processi cognitivi avvenga mediante i sistemi di controllo del corpo; la recente ricerca scientifica ha mostrato e continua a mostrare interessanti interazioni tra funzioni cognitive superiori e sistema sensori-motorio (Caruana & Borghi, 2013). Due le principali prospettive *embodied*: una di matrice percettiva e una di matrice motoria, che non devono essere viste come alternative l'una all'altra, ma come complementari; si tratta semplicemente di porre una maggior enfasi sull'uno o sull'altro dei due aspetti dell'esperienza.

Lo sviluppo della cognizione (compreso quello del linguaggio) si innesta nel più ampio sviluppo sensori-motorio. La cognizione emerge pertanto in tempo reale grazie e attraverso l'interazione "fisica" del bambino con l'ambiente circostante (Gogate & Hollich, 2010; Hockema & Smith, 2009). I bambini percepiscono informazioni che sono già disponibile nell'ambiente e, allo stesso tempo, agiscono nell'ambiente e lo cambiano e questo genera nuove informazioni da raccogliere. Così facendo i bambini fanno esperienze "istantanee" delle connessioni tra i loro movimenti e i cambiamenti nell'ambiente generati da quegli stessi movimenti. Su questi processi di percezione-azione si pongono le basi per successivi sviluppi che riguardano sempre più complesse relazioni tra il bambino e l'ambiente (Smith & Gasser, 2005). Questi principi sono in linea con le più recenti evidenze neuroscientifiche che suggeriscono che i differenti segmenti del corpo e le azioni in cui essi sono coinvolti vengono rappresentati a livello cerebrale in una serie di schemi corporeo-motori. Lo sviluppo di questi schemi è determinato e modellato dalle interazioni sensori-motorie quotidiane con l'ambiente e risulta fondamentale per l'esecuzione di qualsiasi azione, ma anche per la comprensione delle azioni e del linguaggio che le descrive (Pulvermuller & Fadiga, 2010). Sappiamo, grazie alla scoperta dei neuroni specchio (Rizzolati & Craighero, 2004) che l'area motoria del cervello si attiva non solo quando eseguiamo un'azione, ma anche quando semplicemente osserviamo un'azione. Si pensa che questi circuiti cerebrali dell'area motoria siano collegati all'apprendimento tramite imitazione e allo sviluppo linguistico in quanto possono offrire un primo significato *embodied* alle strutture linguistiche. Su questa idea si fondano alcune recenti ricerche che hanno indagato le relazioni tra competenze motorie e specifici vocabolari *embodied*; ad esempio, tra le competenze fino-motorie e il vocabolario definito BOI (body-object interaction), costituito da parole che si assume contengano una maggiore connotazione motoria (Suggate & Stoeger, 2014), o tra l'età di comparsa del cammino e il successivo vocabolario spaziale, considerando anche il possibile effetto di mediazione delle dinamiche esplorative (Oudgenoeg-Paz et al., 2015, 2016).

La teoria dei sistemi dinamici di sviluppo

La teoria dei sistemi dinamici di sviluppo ha raccolto e rielaborato le idee di autori precedenti, tra cui meritano di essere citati, per il sostanziale apporto offerto, Bernstein e i coniugi Gibson.

Bernstein (1967) parte dalla considerazione che, nonostante le numerosissime possibilità di movimento (garantite dalle quasi infinite possibili combinazioni neuromuscolari) nello sviluppo emerge soltanto un numero relativamente limitato e stabile di *pattern* motori (ad esempio, flettere e distendere gli arti inferiori per camminare, estendere il braccio e afferrare, etc.). L'interpretazione che offre l'autore è che in realtà il sistema nervoso centrale non controlla i singoli elementi del movimento (muscoli e articolazioni), ma strutture coordinative cioè unità funzionali che coinvolgono solo alcuni degli elementi presenti nel sistema muscolo-articolare e che si coordinano in modo relativamente fisso. Si instaurano pertanto dei legami preferenziali all'interno di specifiche combinazioni muscolo-articolari che danno vita a *pattern* stabili. Bernstein punta l'attenzione sulla funzione del movimento più che sullo schema di realizzazione di un movimento, con un rovesciamento di prospettiva rispetto ai precedenti modelli interpretativi (Gesell, 1928; McGraw, 1943). Ne consegue che è la dinamica del movimento ad istruire il sistema nervoso e non il contrario.

La psicologia ecologica, proposta dai coniugi Gibson (Gibson, 1969, 1988; Gibson & Walker, 1984; Gibson & Pick, 2000), si focalizza sul binomio percezione-azione e analizza in profondità la capacità del bambino di estrapolare informazioni attraverso l'esplorazione delle caratteristiche dell'ambiente e di utilizzare tali informazioni per organizzare la propria azione motoria. Da evidenziare che le dinamiche esplorative sono esse stesse sequenze complesse di movimenti attraverso cui i bambini interagiscono con l'ambiente circostante. Il binomio percezione-azione è pertanto un processo circolare continuo: l'esplorazione si struttura partendo dalle esperienze motorie in quanto lo sviluppo delle abilità motorie contribuisce e supporta i comportamenti esplorativi, che a loro volta sfociano in nuove o rinnovate abilità motorie (i principi gibsoniani ispirano anche l'*embodied cognition*).

Sulla scia di queste sollecitazioni, diversi autori provenienti da ambiti disciplinari diversi elaborano un nuovo modello interpretativo che punta al superamento delle visioni parcellizzate del corpo e del movimento, nonché dei classici dualismi struttura *versus* funzione, mente *versus* corpo, apprendimento *versus* sviluppo: la teoria dei sistemi dinamici dello sviluppo (Kelso et al., 1980; Thelen, Kelso, & Fogel, 1987; Thelen & Fogel, 1988; Thelen & Smith, 1993).

In questo modello, il corpo è protagonista del percorso di sviluppo del bambino alla pari della psiche e dell'ambiente: al variare del corpo (su un piano strettamente fisico), varia la percezione degli oggetti, delle persone e dell'ambiente circostante e, di conseguenza, varia qualsiasi azione fatta da quel corpo sulla base di quelle specifiche percezioni. Il comportamento adattivo è dunque caratterizzato da una interazione dinamica tra tre sistemi, essi stessi dinamici: corpo (con le sue caratteristiche biomeccaniche, muscolo-scheletriche e nervose), ambiente (spazio, tempo, oggetti e persone) e sistema nervoso (SN). Diversi principi connotano l'interazione tra i tre sistemi; tra questi, la dinamicità e l'interdipendenza risultano caratterizzanti e fanno sì che al modificarsi di un sistema anche gli altri si modifichino di conseguenza, in una relazione di reciproca dipendenza. In età evolutiva questo continuo riassestamento sistemico caratterizza la quotidianità: le costanti modifiche del corpo (su un piano staturale e ponderale) influenzano la percezione dell'ambiente circostante; parallelamente il SN si modifica (anche) in funzione di questi cambiamenti del corpo e degli *input* ambientali che il corpo rielabora sulla base delle percezioni raccolte. Il percorso evolutivo diventa quindi il percorso di acquisizione di una particolare competenza: la flessibilità (Adolph, 2019), la sola in grado di supportare adeguatamente la ridefinizione continua di sempre nuovi equilibri dinamici e di guidare il bambino nel suo agire in un ambiente che, di fatto, è in continuo cambiamento. Un'ulteriore caratteristica dei sistemi dinamici di sviluppo è la non-linearità; lo sviluppo consiste in una progressione graduale e continua, che può fluttuare laddove anche un piccolo cambiamento può produrre un effetto di ampia portata. Lo sviluppo diventa un processo continuo di auto-ri-organizzazione, in cui il sistema-bambino sfrutta le proprie risorse (corporee, energetiche, cognitive, fisiche, emotive...) per tentare e ritentare fino a giungere a un *pattern* motorio strutturato, efficace ed efficiente per quel particolare momento in quella particolare situazione; appena interviene un cambiamento nel corpo o nello spazio ecco che il *pattern* deve essere nuovamente ripreso e adattato.

Le caratteristiche-chiave dello sviluppo motorio

Nella prospettiva teorica dei sistemi dinamici, una recente sintesi di Adolph e Hoch (2019) sullo sviluppo motorio ne illustra quattro caratteristiche-chiave, che rappresentano anche quattro prospettive con cui studiare lo sviluppo motorio stesso in relazione allo sviluppo degli altri domini. Le autrici le descrivono attraverso questi quattro aggettivi: *embodied*, *embedded*, *enculturated* ed *enabling*.

Affermare che lo sviluppo motorio è *embodied* significa considerare *in primis* che cambiamenti di qualsiasi sorta che riguardano il corpo determinano modifiche del livello di prestazione motoria (Garciaguirre et al., 2007; Rochat et al., 1999). Imparare a muoversi, come abbiamo già evidenziato nel paragrafo precedente, implica imparare ad adattare i propri movimenti alle condizioni fisiche e biomeccaniche del proprio corpo in un particolare momento in cui si impara o si esegue un particolare movimento. In questa interazione corpo-movimento la flessibilità, sostengono le autrici è imperativa, soprattutto in età evolutiva quando il corpo è soggetto a continui cambiamenti. Le modifiche del corpo, infatti, determinano redistribuzioni della massa muscolare e cambiamenti nella forza muscolare e nell'elasticità, e questo cambia di conseguenza le modalità con cui si esegue un determinato compito motorio. In sintesi, imparare a muoversi significa imparare ad adattare i propri comportamenti motori allo 'stato corrente' del proprio corpo.

Affermare che lo sviluppo motorio è *embedded* presuppone considerare che il movimento avviene sempre in un ambiente, in uno spazio e in un tempo definiti; pertanto il movimento è sempre situato. Al variare dell'ambiente fisico, varia la risposta motoria; inoltre nuove e/o rinnovate competenze motorie rendono disponibili nuove opportunità offerte dall'ambiente (Gibson, 1988; Gibson & Pick, 2000). Per questo (e di nuovo) corpo e movimento devono essere in grado di dare risposte dinamiche e flessibili. Centrale nella prospettiva *embedded* è il concetto di *affordance* proposto da Gibson (1988), definibile come la forma che assume l'incontro tra il corpo e l'ambiente e che rende possibile una determinata azione (Franchak & Adolph, 2014). Per fare alcuni esempi, la stessa pendenza può essere gestita con una sequenza di passi o di arrampicata a seconda delle dimensioni e delle caratteristiche del corpo e degli arti, e dell'esperienza motoria del bambino; ancora, sono il livello di destrezza fine della mano e di coordinazione oculo-manuale che determinano se un cucchiaio è semplicemente un oggetto da sbattere o uno strumento per raccogliere il cibo da una ciotola e portarlo alla bocca (Barrett et al., 2007; Connolly & Dalgleish, 1989).

Affermare che lo sviluppo motorio è *enculturated* presuppone considerare che le esperienze motorie avvengono in un ambiente socialmente connotato; le influenze sociali (la presenza/assenza di un caregiver, essere a casa o all'asilo nido) non possono essere considerate come costanti, ma sono di fatto variabili che sostengono o ostacolano l'acquisizione e lo sviluppo di una competenza. Ad esempio, è molto più probabile che un bambino dia avvio ai suoi primi passi se, ad attenderlo a pochi metri di distanza, ci sono le braccia aperte di mamma o di papà; in questa particolare situazione, la postura dei genitori funge da stimolo e da guida per le azioni del bambino (Adolph & Hoch, 2019). Ancora, i genitori possono supportare o contrastare i comportamenti motori sulla base di come organizzano l'ambiente in cui il loro bambino cresce; se in casa è presente una rampa di scale, la collocazione o meno di un cancelletto determina due contesti di esperienza completamente diversi che influenzeranno l'abilità del bambino nella gestione delle scale, almeno dei primi anni di vita. Ciò che può influenzare lo sviluppo motorio non si colloca solo a livello sociale, ma anche a livello culturale; dal momento che lo sviluppo motorio è *embodied* e *embedded*, le differenze antropometriche e quelle culturali nelle pratiche quotidiane condizionano, ad esempio, la sequenza e l'età in cui i bambini acquisiscono i principali *milestones* motori o sviluppano specifiche competenze motorie; ad esempio, i bambini giamaicani iniziano a camminare ad un'età media di circa 10 mesi (Hopkins & Westra, 1990), cioè circa 10-12 settimane prima dei bambini americani (Walle & Campos, 2014) e 12-18 settimane prima dei bambini cinesi (He et al., 2015).

Infine, affermare che lo sviluppo motorio è *enabling*, significa farlo uscire dall'isolamento in cui spesso viene confinato per connetterlo con gli sviluppi propri di altri domini. Il modello dei sistemi dinamici di sviluppo ha messo in evidenza che le competenze motorie (1) possono dare avvio a processi che guidano i bambini nell'apprendimento di come funzionano gli oggetti, di come avvengono determinati eventi o agiscono le persone; (2) promuovono e sostengono lo sviluppo di altre competenze perché nuove abilità motorie non solo offrono nuove opportunità di apprendimento, ma richiedono anche la messa in campo di nuove soluzioni. Nella prospettiva *enabling*, risulta centrale il concetto di cascata di sviluppo: l'acquisizione di un'abilità motoria può innescare una sequenza a cascata il cui effetto può essere vicino nel tempo, ma anche talmente lontano dal comportamento motorio di origine da apparire a malapena collegato. Per esempio, fino a poco fa nessuno avrebbe mai pensato che la capacità di mantenere la postura seduta e di esplorare manualmente gli oggetti a 5 mesi potessero essere collegate con le prestazioni cognitive tra i 4 e i 10 anni e con il rendimento scolastico a 14 anni (Bornstein et al., 2013). La ricerca di questi effetti a cascata ha orientato molti degli studi che hanno indagato (e continuano ad indagare) le relazioni tra sviluppo motorio e sviluppo linguistico, che costituiscono il campo di indagine di questa tesi. I risultati hanno messo in evidenza il diverso contributo di abilità motorie globali (ad es., Longobardi et al., 2014; Wang et al., 2003) e specifiche (ad es., He et al., 2015; Walle & Campos, 2014; Wu et al., 2021), in bambini con sviluppo tipico (ad es., Moore et al., 2019; Oudgenoeg-Paz et al., 2012, 2015, 2016) e atipico (Sansavini et al., 2021; Zuccarini et al., 2017; West et al., 2019), con effetti sia sul breve (ad es., Libertus & Violi, 2016) che sul medio-lungo termine (Collett et al., 2018; Lüke et al., 2019). La sintesi di una parte di questi studi verrà presentata nella revisione sistematica della letteratura che costituisce il secondo capitolo della tesi.

Relazioni tra sviluppo motorio e sviluppo linguistico nei primi anni di vita. Stato dell'arte e questioni aperte

Nell'ultimo ventennio, le relazioni tra sviluppo motorio e sviluppo linguistico nei primi anni di vita hanno suscitato l'interesse di numerosi ricercatori. I risultati di numerosi studi hanno messo in evidenza che questi due domini di sviluppo sono molto più interconnessi di quanto si pensasse in precedenza.

Nel 2010 un articolo pubblicato da Iverson ha fatto sintesi su quanto fino ad allora era emerso rispetto alla relazione movimento-linguaggio. Iverson parte dal sostenere che l'emergere del linguaggio avviene contestualmente all'emergere di una vasta gamma di competenze motorie, che cambiano in via sostanziale il modo in cui i bambini interagiscono con l'ambiente, gli oggetti e le persone. Pertanto, lo sviluppo linguistico non può essere considerato disgiunto dal corpo nel quale lo sviluppo del linguaggio si situa. I ragionamenti proposti da Iverson (2010) tengono in considerazione due aspetti, entrambi importanti per pensare questa relazione: (1) l'acquisizione e l'affinamento di alcune competenze motorie nei primi anni di vita offrono ai bambini l'opportunità di praticare altre competenze importanti per lo sviluppo del linguaggio, anche prima che ne abbiano bisogno a questo scopo; (2) l'emergere di nuove competenze motorie cambia l'esperienza che i bambini hanno/possono avere con gli oggetti e le persone, e la cambia in un modo che risulta essere rilevante per lo sviluppo in generale, e lo sviluppo comunicativo in particolare. Ne deriva che la relazione non è pensata come causale, ma come partecipatoria (Campos et al., 2000; Iverson, 2010); è il principio che Haith (1990) chiama del *partial accomplishment* e indica che le competenze motorie non determinano necessariamente l'emergere di altre competenze, ma *possono* contribuire─in alcuni casi anche sostanzialmente─al loro sviluppo.

Tra il 2014 e il 2015 i primi studi riguardanti le relazioni tra sviluppo motorio e sviluppo linguistico vengono riportati e commentati all'interno di due revisioni della letteratura, che però partono da prospettive di più ampio respiro in cui la relazione movimento-linguaggio nei primi anni di vita occupa solo uno spazio marginale. La prima (Leonard & Hill, 2014) riguarda le relazioni tra sviluppo motorio e sviluppo sociale e cognitivo nelle popolazioni tipiche e atipiche; la seconda (van der Fels et al., 2015) le relazioni tra competenze motorie e competenze cognitive in bambini e ragazzi tra i 4 e i 16 anni di età. I due lavori consentono comunque di supportare empiricamente alcuni dei principi fondanti la teoria dei sistemi dinamici di sviluppo: (1) competenze motorie povere sono spesso associate a disfunzioni dello sviluppo comunicativo-linguistico e sociale; (2) lo sviluppo motorio può condizionare lo sviluppo del bambino in tutti i domini di sviluppo; (3) le competenze motorie possono innescare effetti a cascata con ricadute anche sullo sviluppo linguistico. Parallelamente, queste considerazioni aprono nuove questioni: quali tipi di competenze motorie (grosso- *versus* fino-motorie) possono avere un effetto maggiore sullo sviluppo linguistico? Il potenziale effetto delle competenze motorie sullo sviluppo linguistico cambia nel tempo, e come? Quali abilità linguistiche (tutte *versus* alcune in particolare) possono essere maggiormente condizionate da quali competenze motorie? Quali tipi di meccanismi/processi a cascata possono sottendere relazioni tra sviluppo motorio e sviluppo linguistico?

Nel 2019, nel tentativo di rispondere ad una di queste domande, Gonzalez *et al.* pubblicano una revisione sistematica della letteratura con l'obiettivo di evidenziare se le abilità grosso-motorie e quelle fino-motorie contribuiscono in maniera diversa allo sviluppo delle abilità linguistiche dai primi mesi di vita ai 6 anni. Le autrici concludono affermando che le competenze grosso- e fino-motorie offrono al bambino diverse possibilità di interazione con l'ambiente circostante, e conseguentemente possono attivare diversi effetti a cascata sulle abilità linguistiche, ma che non è possibile affermare che una delle due categorie di competenze offra un contributo più significativo dell'altra. Nelle conclusioni della rassegna vengono descritti e analizzati due possibili effetti a cascata attivati da due specifiche abilità motorie: il cammino e l'afferrare. Da qui l'idea, che caratterizza questo progetto di ricerca, di focalizzare l'attenzione sulla specificità di possibili relazioni tra sviluppo motorio e sviluppo linguistico, tenendo in considerazioni anche altre questioni aperte come quella riguardante l'andamento nel tempo di tali relazioni, come dettaglieremo nel prossimo paragrafo.

Il progetto di ricerca

Partendo dalle questioni ancora aperte e da quelle che sino ad ora sono state affrontate in maniera marginale, il presente progetto di ricerca è stato pensato e strutturato attorno a quattro elementi.

Il primo riguarda la specificità della relazione tra competenze motorie e competenze linguistiche. Sulla base dell'analisi della letteratura ci siamo orientati su un'indagine che consideri, rispetto al dominio motorio, competenze specifiche piuttosto che misure di sviluppo globale, siano esse schemi motori (come il gattonamento o il cammino) o capacità coordinative (come la coordinazione dinamica generale o l'equilibrio); anche sul piano linguistico, nello studio che coinvolge i bambini più grandi abbiamo differenziato la comprensione/produzione di nomi e predicati e il vocabolario spaziale (parole che possono essere più facilmente associate alle azioni e alle esperienze motorie). L'ipotesi è che questi ultimi possano essere maggiormente influenzati dalle competenze motorie in virtù del loro "etichettare verbalmente" le esperienze motorie stesse.

Il secondo elemento riguarda la fascia d'età in cui collocare l'indagine, privilegiandone due che in letteratura sono state fino ad ora meno indagate. Il primo studio si colloca infatti nel periodo a cavallo tra il primo e il secondo anno di vita, caratterizzato sul piano motorio dalla comparsa della locomozione autonoma (gattonamento e avvio del cammino), e sul piano linguistico dalla comparsa dei gesti comunicativi, dallo sviluppo del primo vocabolario recettivo e dalla comparsa delle prime parole (spesso in forma bimodale, accompagnate da un gesto). Il secondo studio si colloca invece nel periodo a cavallo tra il secondo e il terzo anno di vita. In questa fascia d'età i principali schemi motori sono già stati acquisiti, ma gli stessi devono ancora essere affinati; entrano in gioco le capacità coordinative, competenze finalizzate a rendere i movimenti efficaci ed efficienti. Per questo abbiamo considerato, oltre ad una misura globale di sviluppo motorio, alcune misure per valutare specifiche capacità coordinative sia grosso- che fino-motorie e il loro possibile impatto su specifiche competenze linguistiche.

Il terzo elemento riguarda le prospettive sullo sviluppo motorio assunte a riferimento tra quelle proposte da Adolph e Hoch (2019). Abbiamo cercato di considerarle tutte e quattro, seppur in combinazioni diverse nei due studi. Nello specifico, il primo studio assume principalmente le prospettive *enabling* e *enculturated*; la prima orienta le ipotesi che riguardano i legami tra l'avvio della locomozione autonoma (che può innescare effetti a cascata nello sviluppo del bambino) e il concorrente/successivo sviluppo comunicativo-linguistico tra gli 8 e i 16 mesi; la seconda orienta invece le ipotesi su come la locomozione autonoma possa influenzare il linguaggio che i genitori rivolgono ai loro bambini e sulle possibili interazioni della competenza motoria con fattori individuali e sociali nel favorire lo sviluppo linguistico del bambino. Il secondo studio assume invece le prospettive *embodied* ed *embedded* su cui poggiano le ipotesi che alcune competenze motorie, come l'organizzazione spaziale, possano sostenere maggiormente l'acquisizione di alcune competenze linguistiche, ad esempio il vocabolario spaziale.

Il quarto riguarda gli intervalli di tempo in cui collocare le indagini. Gli studi precedenti hanno indagato relazioni sia concorrenti che longitudinali; rispetto a queste ultime, le indagini si sono concentrate o nel breve periodo (considerando le settimane immediatamente precedenti/successive la comparsa della competenza motoria considerata) o nel lungo periodo (l'avvio della competenza motoria e il suo effetto a 18, 24 o 36 mesi e oltre). Pochi studi hanno considerato il breve-medio periodo (quattro-sei mesi), che invece caratterizza entrambi i nostri studi, e ci ha consentito di analizzare sia relazioni concorrenti che longitudinali.

Struttura della tesi

La tesi è strutturata nella presente Introduzione (di carattere generale), tre capitoli, e le Conclusioni.

Il primo capitolo presenta una *systematic review* della letteratura che, attraverso l'analisi degli studi sul tema pubblicati negli ultimi vent'anni, ha cercato di rispondere a due quesiti: (1) se e come le relazioni tra sviluppo motorio e sviluppo linguistico cambiano nel tempo; (2) quali percorsi caratterizzanti lo sviluppo del linguaggio sono innescati da quali competenze motorie.

Il secondo capitolo presenta un primo studio empirico che esplora il potenziale contributo della locomozione autonoma (gattonamento e cammino) allo sviluppo linguistico tra gli 8 e i 16 mesi di vita. E' costituto da due diversi studi. Lo Studio 1 utilizza due misure di performance, una per il gattonamento e una per il cammino, valutate a 8, 12 e 16 mesi; la performance è stata definita su tre livelli sulla base di un modello teorico in cui lo sviluppo motorio si manifesta attraverso cambiamenti graduali (in termini di efficacia ed efficienza) dello schema di movimento. Il linguaggio è misurato attraverso il repertorio di gesti comunicativi (a 8 e 12 mesi), il vocabolario recettivo globale (a 12 e 16 mesi) e il vocabolario produttivo (a 16 mesi). Lo studio 2 indaga se, e come, le due forme di locomozione già considerate nello studio precedente (gattonamento e cammino) possono influenzare l’input verbale rivolto dai genitori al bambino durante l’interazione. L’input verbale è misurato in termini di caratteristiche strutturali e funzioni comunicative a 8, 12 e 16 mesi. Inoltre, approfondisce i risultati emersi nello Studio 1 testando alcuni modelli predittivi dello sviluppo linguistico del bambino che tengano in considerazione la competenza di locomozione autonoma e alcuni fattori individuali (genere e competenze linguistiche precedenti) e sociali (misure di quantità e qualità del linguaggio dei genitori), che dalla letteratura sappiamo poter essere rilevanti nell’acquisizione del linguaggio.

Il terzo capitolo presenta un secondo studio che indaga longitudinalmente la relazione tra sviluppo motorio e sviluppo linguistico a cavallo tra il secondo e il terzo anno di vita, utilizzando misure motorie sia globali che specifiche a 18 e 24 mesi, e misure linguistiche sia globali che specifiche sei mesi dopo, a 24 e 30 mesi rispettivamente. Le variabili motorie specifiche sono capacità coordinative, non più *milestones* come nello studio precedenti; le variabili linguistiche specifiche sono categorie linguistiche che, nelle nostre ipotesi, risultano essere maggiormente legate alle azioni motorie, come i predicati, o all'esperienza motoria, come il vocabolario spaziale.

Infine, nelle Conclusioni vengono sintetizzati i principali risultati, i limiti, e le direzioni future della ricerca.

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CAPITOLO 1

Deepening the understanding of the links between motor and language development in infancy and early childhood: A systematic review

Introduction

Several recent studies have explored cross-domain interactions between motor and language development using a dynamic systems approach and an embodied cognition approach to development (Gibson, 1988; Gibson & Pick, 2000; Thelen, 1995; Thelen & Smith, 1994). Results show that the motor and language domains are more interrelated than has previously been thought, both in typically developing children (e.g., Walle & Campos, 2014; Valla et al., 2020) and children with developmental disorders (e.g., Houwen et al., 2016; LeBarton & Landa, 2019). In particular, Iverson (2010) highlighted specific aspects of motor and language development that appear to be closely paired, such as increased rhythmic arm movements and reduplicated babble in infants or emergent object displacement during daily play and the later vocabulary spurt in toddlers. Increasing rhythmic arm movements during the onset of reduplicated babble (Eilers et al.,1993; Ejiri, 1998; Iverson et al., 2007; Locke et al.,1995) suggests that this motor experience – especially when the movement also produces a sound (e.g., when using a rattle or banging with an object) – may present an opportunity for practising a structure of rhythmic and synchronized movements of the sort required in babbling. Indeed, when infants perform such "sound movements", they perceive their own rhythmic movement and the rhythmic sound that is time-locked to these movements. Reduplicated babbling entails the same type of correlation between movement and sound as when infants' oro-motor rhythmic movements are time-locked to rhythmic sounds. Furthermore, the ability to act on objects in an increasingly sophisticated manner offers the opportunity to notice more specific object features and thereby attribute more specific (embodied sensorimotor) meanings to those objects (Lifter & Bloom, 1989). This latter ability may facilitate mapping particular meanings to specific referents, which is particularly important in learning words (Iverson, 2010). For typically developing children in a typical environment, motor skills – especially at their onset – trigger a cascade of events that drastically change the child's everyday experiences with their bodies, objects, and people, and engender opportunities for acting and learning in all developmental domains (Gibson,1988).

Some of the first studies on the relationships between motor development and language development published before 2015 were included in two previous reviews (Leonard & Hill, 2014; van der Fels et al., 2015) and one editorial (Libertus & Hauf, 2017). However, these reviews dealt with broader issues, such as the links between motor development and social and/or cognitive development in typical and atypical populations. A more focused review of the links between developing motor skills (what these skills enable the child to do) and language development is still lacking. The findings of the current review support the following ideas. First, poor motor development underlies developmental disorders in language, communication, and social interaction. Second, the development of motor skills affects child development across several domains. Third, motor skills may activate cascading developmental effects, which could support advances in language. However, these ideas raise the following further questions. What types of motor skills (gross *versus* fine) may have a larger effect on the language domain? Do any cascading effects of motor skills on language development change over time, and if so, how? Which language abilities (all of them or particular ones) could be fostered? What mechanisms underlie the links between motor and language development?

In order to address one of these questions, Gonzalez et al. (2019) published a systematic review aimed at discerning whether gross and fine motor skills make different contributions to language outcomes across infancy and early childhood. They found that gross and fine motor skills enable different types of children's interactions with space, objects, and people and may trigger cascading effects on language acquisition. However, based on the evidence, it is impossible to state whether advances in which skills – gross or fine – are more important for language outcomes. This is due to the variety of measures used, inconsistencies in the findings, and the paucity of studies investigating fine motor skills. In concluding, Gonzalez et al. (2019) speculated that it is likely that both gross and fine motor skills may support language via different mechanisms. For instance, walking enables children to move easily in their environment, reach for objects (both close and distant) and use them in communicative exchanges with their caregivers. The latter, in turn, offers them linguistic input about their current focus of attention (Clearfield, 2011; Karasik et al., 2014). On the other hand, fine motor manipulation, such as grasping and drawing, allows children to explore objects in depth and perceive their physical and functional features. This may give caregivers opportunities to label object features and support the child's language learning via fast-mapping processes. Following Gonzales et al. (2019), it seems that particular motor skills such as walking or manipulation can explain how motor skills may activate cascading effects on the language domain better than broad categories of motor skills such as gross and fine motor skills.

As Gonzalez et al. (2019) have already addressed the first question raised in this paper, we address the remaining three questions by presenting a systematic review of the studies that have investigated the relationships between specific motor skills and specific language abilities in typically developing children, to offer a better understanding of the mechanisms underlying these relationships. More specifically, the review aims to investigate three questions. These are, first, whether and how potential cascading effects of motor skills on language development change over time, which types of language abilities (all or some in particular) could be fostered, and what mechanisms underlie the links between motor and language development. We limited our search to studies that measured motor development in the first three years of life, as previous work indicates that the major motor achievements in this age range (e.g., the onset of sitting and walking) may trigger possible cascading effects on language development (e.g., Libertus & Violi, 2016; Oudgenoeg et al., 2012; Walle & Campos, 2014).

Method

Study Design

The process of searching and identifying relevant literature on the topic was conducted systematically, following PRISMA guidelines (Liberati et al., 2009; Moher et al., 2009).

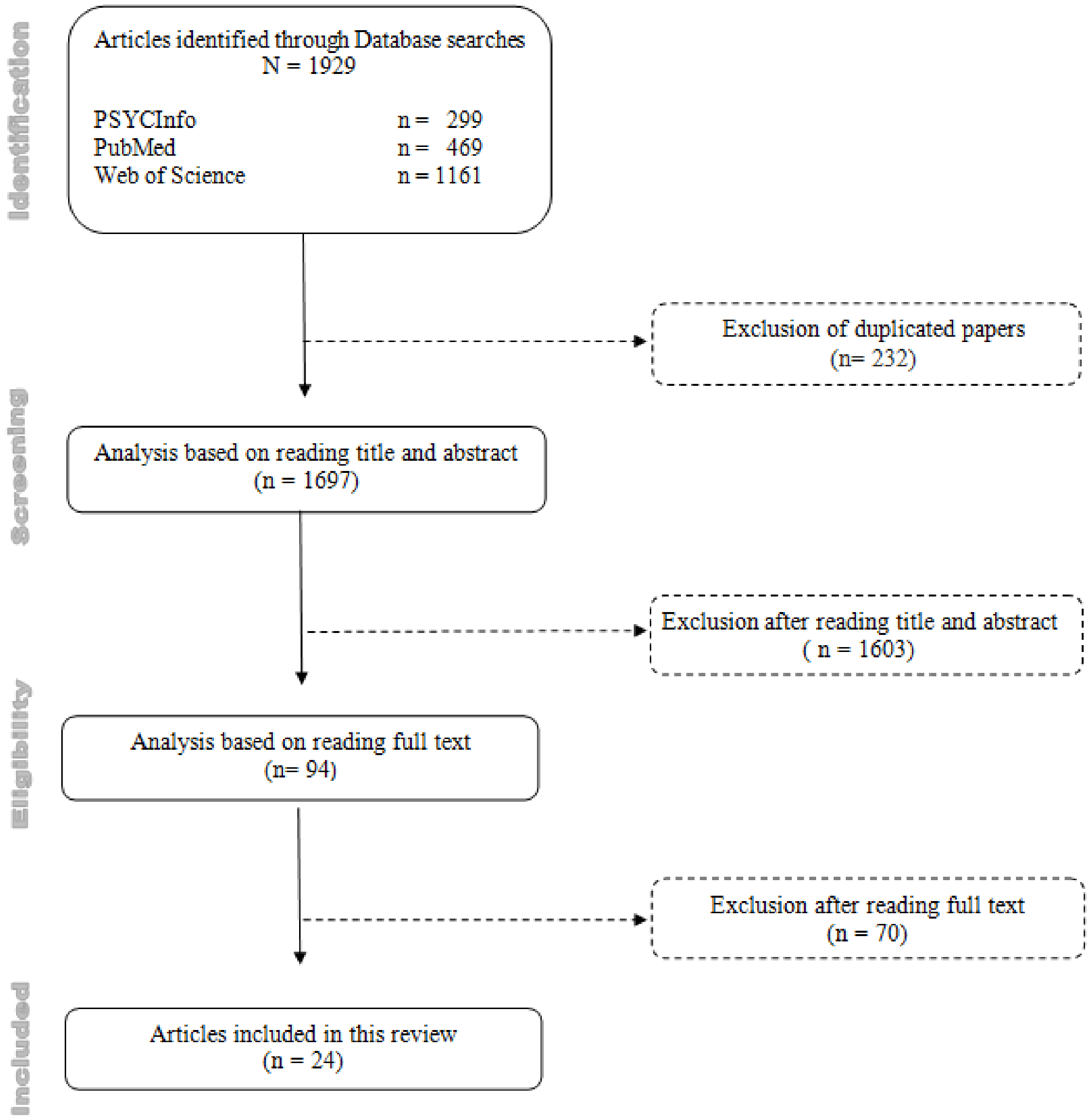
Search Strategy

First, we defined the search terms. In line with our goal, we drafted a detailed checklist of motor skills, starting from the literature on early motor development (e.g., Adolph & Berger, 2015; Adolph & Hoch, 2019; Adolph & Robinson, 2015;

Adolph & Tamis-LeMonda, 2014; Exner, 2010; Gallahue et al., 2012). The following search terms for motor skills were used: head control, sit*, stand*/upright posture, turn*/roll*, climb*, crawl*, creep*, walk*, run*, jump*, throw*, balance, ball-skill*, spatial-temporal/spatial organization, general dynamic coordination, visual-motor coordination, reach*, catch*, grasp*, manipulation, pincer grip, bimanual coordination/bilateral hand use, manual dexterity, visual-motor integration, handedness/hand preference, laterality. We also used more general terms such as motor development, motor performance, motor control or psychomotor development because some studies that used global scores in main analyses offered details on single motor behaviors in the Results section or Supplementary Materials. Motor terms were combined with the following search terms addressing language development and specific language abilities: receptive vocabulary, productive/expressive vocabulary, comprehension, communication skill*, communicative gesture*, babbling, and vocalization*. The databases used were PsycInfo, PubMed, and Web of Science. The search limits were set to English language, peer-reviewed papers (when this option was available), publication data from January 2000 to December 2021, and human studies. The records (1929) were checked for duplicates. The resulting articles (1697) were further selected by applying four inclusion criteria after reading the title and the abstract. To be selected, studies had to involve typically developing children, to investigate the links between motor skills measured in the first three years of life and concurrent and/or later language abilities, to focus on specific motor skills (not global scores of motor abilities) and be empirical research papers (i.e., not merely theoretical studies). In addition, four exclusion criteria were used, as follows. The first is studies with special populations, except where the Method section showed that a special population sample was compared with a typically developing sample, in which case we considered only the results of the typical comparison group. The others were studies investigating an inverse relation, starting from language abilities, studies in which measures of motor skills regarded only speech-motor/oro-motor control and case studies, intervention studies, and studies focused only on the description of motor and language developmental trajectories. The resulting articles (94) were further selected by reading the full text. The first author conducted the search and selected the articles. In cases of doubt, the other authors were consulted. The final set included 24 papers. The whole selection process is reported in Figure 1.

Figure 1

PRISMA Flow Diagram of the Selection Process



Risk of Bias Assessment

The quality of the studies was evaluated according to a modified version of QUIPS (Quality in Prognosis Studies), a standardized tool used to assess the risk of bias (Hayden et al., 2013). The modified version is organized in six parts, one for each domain that previous work (Hayden et al., 2006) had identified as fundamental to consider when evaluating validity and bias in research studies: Study participation, Study attrition, Motor measurement, Language measurement, Study confounding, and Statistical analysis and reporting. To grade the risk of bias, each of the six potential bias domains is rated as having a high, moderate, or low risk of bias according to whether it did not meet, respectively, partially met, or fully met the *criteria*. Selected papers were evaluated as having a "Low to Moderate risk" of bias if they were graded as low or moderate in all six bias domains and "High risk" if they were graded as high in more than two bias domains. The first author completed the risk of bias assessment of all selected articles except those in which she or other authors of the present review were involved; these articles were assessed by a second external reviewer. No studies were excluded based on the QUISP assessment. The results of the risk of bias assessment are reported in Table 1.

Data Extraction and Synthesis

A final pool of 24 papers was obtained. The following data were extracted: authors and year of publication, sample size, study design, age of assessment, motor measures, language measures, and main results. The studies were grouped and reported in the Results section according to the focus on gross motor skills or fine motor skills. Nineteen studies measured gross motor skills and eleven measured fine motor skills; six studies measured both gross and fine motor skills and are included in both sections.

Table 1

Risk-of-bias Assessment of the 24 Selected Papers

Risk of bias

- Low (white)
- Moderate (grey)
- High (black)

	Study Participation	Study Attrition	Motor Measurement	Language Measurement	Study Confounding	Statistical Analysis and Reporting	Low to Moderate Risk of Bias
Andalò et al. (2021)	Moderate	Low	Low	High	Low	Low	
Berger et al. (2017)	Moderate	Low	Low	Low	Moderate	Low	√
Bradshaw et al. (2018)	High	Low	Low	Low	Moderate	Low	
Clearfield (2011)	High	Low	Low	Low	High	Moderate	
Cochet (2011)[a]	High	Low	Low	Low	Moderate	Moderate	
Collett et al. (2018)	Moderate	Moderate	Low	High	Moderate	Moderate	
Esseily et al. (2010)	High	Low	Low	Low	High	Low	
Gonzales et al. (2020)	Low	Moderate	Low	Low	Low	Low	√
He et al. (2015)	Low	Low	Low	Low	Low	Low	√
Karasik et al. (2014)[a]	Low	Low	Low	Low	Low	Low	√
Libertus & Violi (2016)	Low	Moderate	Low	Low	Low	Low	√
Lüke et al. (2019)[a]	Low	High	Moderate	Low	Low	Moderate	
Moore et al. (2019)	Moderate	Low	Low	Low	Moderate	Low	√
Muluk et al. (2014)	Moderate	Low	Moderate	Moderate	Low	Moderate	
Muluk et al. (2016)	Moderate	Low	Moderate	Moderate	Low	Moderate	√
Nelson et al. (2014)[a]	Low	Low	Low	Low	Low	Moderate	√
Ora-Oudgenoeg-Paz et al. (2012)[a]	High	Moderate	Moderate	Low	High	Low	
Ora-Oudgenoeg-Paz et al. (2015)	Moderate	Low	Moderate	Low	Moderate	Low	√
Ora-Oudgenoeg-Paz et al. (2016)	Moderate	Low	Low	Low	Moderate	Low	√
Walle (2016)	Moderate	Moderate	Low	Low	Low	Low	√
Walle & Campos (2014)	Moderate	Low	Low	Low	Low	Low	√
West & Iverson (2021)	Moderate	Low	Low	Low	Low	Low	√
West et al. (2019)	Moderate	Low	Low	Low	Low	Low	√
Wu et al. (2021)	Moderate	Low	Low	Low	Moderate	Moderate	√

Results

Gross Motor Skills

First, we present the main characteristics of the studies focusing on gross motor skills. Then we present results from studies that measured gross motor milestones or gross motor coordination skills. Then we present results from studies that considered single items of gross motor scales. We close the section with a short conclusion.

Main Characteristics of the Studies

Nineteen papers reported findings regarding gross motor skills (Table 2). One paper (Walle & Campos, 2014) presented two studies that are separately described in Table 2. Six studies had a cross-sectional design including an age-held-constant design, 13 a longitudinal design, and one study a mixed design. Regarding motor measures, walking was assessed in most studies (14), sitting in three studies, crawling, standing, and motor coordination skills only in one study (each); single items of gross motor scales were used in three studies. Regarding language measures, global receptive and productive vocabulary were assessed in most studies (14), communicative gestures in five studies, spatial vocabulary in three, vocalizations in four, noun/non-noun or noun/predicate comprehension and production in two, and grammar use in two; single items of language scales were also used in two studies. The sample size was 25 or smaller in four studies, ranged between 26 and 50 in eight studies, between 51 and 100 in four studies, and was larger than 100 in the other four studies. Three samples were comparison groups in studies investigating the relationships between motor and language development in children with developmental disorders.

The studies were conducted in six countries: the United States (n = 12), The Netherlands (n = 3), Turkey (n = 2), Germany, Italy, and China (n = 1). The Chinese sample was compared with an American sample in a cross-cultural study (He et al., 2015).

Table 2

Main Data Extracted from Studies Included in the Gross Motor Skills Section

Source	N	Study Design	Age tested	Motor measures	Language measures	Main results
Andalò et al. (2021)	36	MIX	Motor: 18 and 24 m/o Language: 24 and 30 m/o	Global gross motor score, general dynamic coordination (GDC), balance, spatial organization, and hand-eye coordination; (GMDS -R 0-2, Locomotor scale)	Global language ability, receptive/productive noun/predicate and spatial vocabulary (GMDS-R 0-2, GMDS-ER 2-8, MCDI-Italian version, PiNG)	At 18 m/o: global gross motor score predicted predicate production, and GDC predicted noun production. At 24 m/o: GDC predicted predicate production.
Berger et al. (2017)	23	L	2-19 m/o (bi-weekly assessments); four selected sessions across the transition to crawling	Postures (e.g., sitting, crawling, and pulling-to-stand; observation)	Vocalizations (e.g., cooing and babbling; observation)	No relationship.
Bradshow et al. (2018)	113	CS	12 m/o	Pre-walking, standing, and walking status (MSEL, selected items of GM scale)	Communicative gestures (conventional and distal gestures) Sounds and words production; CSBS)	No relationship.
Clearfield (2011) Experiment 3	14	L	9-14 m/o (monthly assessments)	Transition to walking (observation)	Communicative behaviors (directed and undirected vocalizations; directed and undirected gestures; observation)	Walking infants used gestures more than crawling infants.

Collett et al. (2018)	158	L	Motor: 7 and 18 m/o Language: 3 y/o	BSID, GM scale (selected items)	Global receptive and productive language (BSID)	At 7 m/o: relationship between a) head control and receptive and productive language; b) independent sitting and productive language. At 18 m/o: no relationship.
He et al. (2015)	US sample=40 Chinese sample=42	CS	US sample: 12,5 m/o Chinese sample: 13-14,5 m/o	Crawling and walking status (parental report)	Global receptive and productive vocabulary; receptive/productive noun/non-noun vocabulary (MCDI, US, and Chinese versions)	Walking infants in both samples had greater receptive and productive vocabularies than crawling infants. In the Chinese sample non-noun vocabulary was differentially positively affected by walking status.
Karasik et al. (2014)	50	CS	13 m/o	Crawling and walking status (observation)	Infants: Global receptive and productive vocabulary, gestures (MCDI) Mothers: response types (affirmations, referential, action directives, No response; observation)	Infants: no relationship Mothers: infants' locomotor status elicited different verbal responses from mothers; mothers of walkers responded with action directives more often than mothers of crawlers.
Libertus & Violi (2016)	29	L	Motor: 3-5 m/o (8 weekly assessments) Language: 10 and 14 m/o	Sitting duration	Global receptive vocabulary (MCDI)	Sitting slope was related to receptive vocabulary at both 10 and 14 m/o and a significant predictor of receptive vocabulary at 10 m/o.
Lüke et al.(2019)	45	L	Motor: behavior onset Language: 12,14,16,18,21,24, 30,36,42,48 (observation sessions) and 12, 24, 36, 48 m/o (assessments with standardized tests)	Walking onset (parental report)	Pointing (observation between 12 and 21 m/o), word and sentence comprehension (SETK-2 and 3-5), global productive vocabulary (MCDI, German version), word and sentence production, and grammar use (PDSS, P-ITPA, SETK-2, and 3-5)	At 24 m/o: walking onset was related to sentence comprehension, word and sentence production, productive vocabulary, and predicted productive vocabulary. At 12, 36 and 48 m/o: no relationship.

Moore et al. (2019)	44	L	6 -17 m/o (monthly assessments)	Walking onset (observation and parental report) Walking score (EQM, selected item of GM scale)	Pointing onset (observation); first five words learned (observation and audio-recording by LENA); global receptive and productive vocabulary (MCDI)	No relationship.
Muluk et al. (2014)	160	CS	3 y/o	DDST II, GM scale (selected items)	DDST II, Language scale (selected items)	"Jumps up" was related to "Comprehends one preposition", "Defines words", and "Gives first and last name". "Balances on foot 2 s" was related to "Knows one function".
Muluk et al. (2016)	505 Group 1: 6 m/o (range 5 to 7, n=162) Group 2: 12 m/o (range 11 to 13, n=127) Group 3: 18 m/o (range 17 to 19, n=101) Group 4: 24 m/o (range 23 to 27, n=115)	CS	6,12,18,24 m/o	DDST II, GM scale (selected items)	DDST II, Language scale (selected items)	At 6 m/o: "Pull to sit, no head lag" and "Lifts chest with arm support" were related to "Turns to sound" and "Turns to voice" At 12 m/o: "Stands holding on" was related to "Mama, dada specific" and "4 words other than mama/dada," and "Stands alone 10 seconds" was also related to "4 words other than mama/dada". At 18 m/o: "Throws ball" was negatively related to "4 words other than mama/dada." 24 m/o: no relationship.
Oudgenoeg-Paz et al. (2012)	55 First cohort=27 Second cohort=28	L	Motor: behaviors onset Language: first cohort 16-24 m/o (every 4 months); second cohort 20-28 m/o (every 4	Sitting and walking onset (parental report)	Productive vocabulary (MCDI Dutch version)	Early age of sitting and walking predicted a higher level and a larger growth of productive vocabulary respectively.

			months)			
Oudgenoeg -Paz et al. (2015)	59 First cohort = 28 Second cohort=31	L	Motor: behaviors onset (sitting=8,35 m/o; walking=15,02 m/o) and 20 m/o Language: 36 m/o	Sitting and walking onset (parent report); exploration through self-locomotion (observation)	Spatial productive vocabulary (specific test)	Early age of sitting and walking predicted spatial productive vocabulary; exploration through self-locomotion partially mediated the walking-language relationship.
Oudgenoeg -Paz et al. (2016)	31	L	Motor: behavior onset and 20 m/o Language: 43 m/o	Walking onset (parent report); exploration through self-locomotion (observation)	Spatial productive vocabulary (specific test), global receptive vocabulary (PPVT-III), grammatical and lexical categories (Sentence repetition task)	Age of walking did not predict any language measures. Exploration through self-locomotion mediated the indirect effect of age of walking on spatial language.
Walle (2016)	43	L	10-12,5 m/o (bi-weekly assessments)	Walking experience (parental report)	Global receptive and productive vocabulary (MCDI)	Walking experience predicted receptive and productive vocabulary. The links between walking status and joint engagement behaviors and parent perception of the infant as an individual were related to receptive but not to productive vocabulary.
Walle & Campos (2014) Study 1	44	L	10-12,5 m/o (bi-weekly assessments)	Walking experience (parental report)	Global receptive and productive vocabulary (MCDI)	Walking experience predicted both receptive and productive language.
Walle & Campos (2014) Study 2	75	CS	12,5 m/o	Infants: crawling and walking status (parental report); amount of movement (observation) Parents: amount of movement (observation)	Infants: global receptive and productive vocabulary (MCDI); vocalizations (observation) Parents: vocalizations (observation)	Walking infants who received more language input from the parent had larger receptive and productive vocabularies, whereas language input was unrelated to receptive and productive vocabulary for crawling infants.

						Walking infants whose parents moved less frequently had larger receptive and productive vocabularies. Walking infants who spent more time at a medium distance from the parent had a larger productive vocabulary, but no such relation was found for crawling infants.
West & Iverson (2021)	25	L	2-19 m/o (bi-weekly assessments); seven selected sessions across the transition to walking	Walking onset (parental report and observation)	Infants: deictic gestures, vocalization (observation) Caregivers: verbal responses (observation)	After learning to walk, the pace of gesture growth (but not vocalization growth) increased substantially, and infants increasingly coordinated gestures and vocalizations with locomotion. Also, caregivers' verbal responses increased and changed qualitatively.
West et al. (2019)	25	L	2-19 m/o (bi-weekly assessments); seven selected sessions across the transition to walking	Walking onset (parental report)	Global receptive and productive vocabulary (MCDI)	The acquisition of walking was related to a significant increase in both receptive and expressive vocabulary.

Note. BSID, Bayley Scales of Infant Development; CR, cross-sectional; CSBS, Communication and Symbolic Behaviour Scales; DDST, Denver Developmental Screening Test; EMQ, Early Motor Questionnaire; GM, gross motor; GMDS, Griffiths Mental Development Scales; L, longitudinal; MCDI, MacArthur-Bates Communicative Development Inventories; MIX, mixed; m/, months old; MSEL, Mullen Scales of Early Learning; PDSS, Patholinguistische Diagnostik bei Sprachentwicklungsstörungen [Patholinguistic Diagnostics for Language Impairments]; PiNG, Picture Naming Game; P-ITPA, Potsdam-Illinois Test für Psycholinguistische Fähigkeiten [Potsdam-Illinois Test of Psycholinguistic Abilities]; PPVT, Peabody Picture Vocabulary Test; SETK, Sprachentwicklungstest für zweijährige Kinder [Language Acquisition test]; y/o, years old.

Gross Motor Milestones

Sitting. Three studies tested the relationships between sitting and later language abilities. Libertus and Violi (2016) found that greater growth in the duration of independent sitting measured between 3 and 5 months of age was significantly related to a larger receptive vocabulary at both 10 and 14 months, even when controlling for concurrent general motor skills. Oudgenoeg-Paz et al. (2012, 2015) measured the age of attainment of unsupported sitting; they found that earlier sitting was significantly related to the growth in general productive vocabulary measured between 16 and 28 months (Oudgenoeg-Paz et al., 2012) and marginally significantly to productive spatial vocabulary measured at 36 months (Oudgenoeg-Paz et al., 2015). Earlier sitting or stronger sitting ability in the first months of life predicted receptive vocabulary at the turn of the first and second year and productive vocabulary at the turn of the second and third year.

Crawling. Only one study (Berger et al., 2017) examined the relationship between crawling and language development. The authors analyzed the trajectories of concurrent motor and vocal behaviors around 8 months at four key time points across the transition to crawling: 2 weeks pre-crawling, crawling onset, two weeks post-crawling, and four weeks post-crawling. They observed 11 postures/movements (e.g., sitting, crawling, pulling-to-stand) and six types of vocalizations (e.g., babbling, cooing, crying). Their findings showed that infants were less likely to produce vocalizations while crawling when they were novice crawlers, but after a month of crawling experience, they were equally like to vocalize while crawling as when not crawling.

Standing. Only one study (Bradshaw et al., 2018) included standing in its investigation of the relationship between walking ability and social communication skills. The study involved 12-months-old infants classified into one of three groups based on their walking ability: walkers (walks independently), standers (stands independently), or pre-walkers (does not yet stand or walk independently). Language measurement included a communicative gesture score (conventional and distal gestures) and a speech score (syllables and words). The results did not show any significant relationship between standing and both language scores.

Crawling to walking. Eight studies considered the transition from crawling to walking. Three of them compared the effect of crawling *versus* walking status on communicative gestures. Bradshow et al. (2018) and Karasik et al. (2014) did not find any significant relationship; in contrast, Clearfield (2011) found that walking infants used gestures (pointing to an object and waving an object) significantly more often than crawling infants. The remaining five studies compared the effect of crawling *versus* walking status on receptive and productive vocabularies at around the age the infants started walking, but the results are inconsistent. Four of these studies (He et al., 2015; Walle & Campos, 2014, Walle, 2016; West et al., 2019) found that the acquisition of walking was related to a significant increase in both receptive and productive vocabulary. He et al. (2015) also examined the features of both receptive and productive vocabulary in relation to noun and non-noun components comparing American and Chinese infants; noun vocabulary was positively affected by the acquisition of walking, but only in the Chinese sample. In contrast to the works mentioned above, two studies (Karasik et al., 2014; Moore et al., 2019) did not find that walkers had larger receptive and/or productive vocabularies than crawlers.

Walking. Five studies focused on the relationship between walking onset and concurrent or later language development. West and Iverson (2021) followed infants longitudinally over seven months during the transition to walking. They found that after the onset of walking, the pace of gesture (but not vocalization) growth increased substantially. Walking infants also showed an increase in the coordination of communicative behaviors (both gestures and vocalizations) with walking: for example, by walking toward a caregiver and showing a toy. Three studies were conducted by Oudgenoeg-Paz and colleagues (2012, 2015, 2016), involving the same sample. The authors tested the relationships between the age of walking onset and, respectively, the growth of general productive vocabulary between 16 and 28 months (2012), productive spatial language at 36 months (2015), and general receptive language, productive spatial language, and use of grammatical and lexical categories at 43 months (2016). Children who achieved independent walking earlier showed higher language competence at the turn of the second and third years; the relationship between walking and language abilities remained significant at 36 months but disappeared at 43 months. Similar results were found by Lüke et al. (2019), who showed significant links between the attainment of walking and language comprehension and production at 24 months but not at 36 and 48 months.

Mechanisms Through which Walking may Promote Language development. Five of the studies mentioned above (Karasik et al., 2014; Oudgenoeg-paz, 2015, 2016; Walle, 2016; Walle & Campos, 2014) also explored some possible mechanisms that may help to explain the links between walking and language development. Oudgenoeg-Paz et al. (2015) found that exploration through self-locomotion partially mediated the relationship between the age of walking onset and spatial vocabulary at 36 months. Some months later, at age 43 months, walking age no longer directly predicted spatial vocabulary, but exploration still significantly mediated the indirect effect of walking onset on spatial language (Oudgenoeg-Paz et al., 2016). Karasik et al. (2014) focused on the impact of infants' walking on caregivers' verbal input. They showed that infants’ locomotor status (crawling *versus* walking) affects how they share objects with their mothers, which in turn elicits different verbal responses from mothers. Indeed, mothers of walkers (who typically display movement-related bids, that is, show or give an object to their caregiver while locomoting) responded with action directives with richer language input more often than mothers of crawlers (who typically bid from stationary positions). Similarly, West and Iverson (2021) observed changes in caregivers' responses during walking learning. In particular, they highlighted that caregivers had more opportunities to respond contingently to their walking infants – who increasingly coordinated their gestures and vocalizations – than crawlers. For example, the infant walked toward a caregiver showing off a toy bear, and the caregiver said: "What did you find? Is that your bear?"). Walle and Campos (2014) explored whether and how three social-environmental aspects (the amount of parent language input, infants' proximity to the parent, and the amount of both parent and infant movements during a free play session) were related to infants' language development as a function of locomotor status (crawling versus walking). Their three findings were as follows. Walking infants who received more language input from the parent had larger receptive and productive vocabularies, whereas for crawling infants language input was unrelated to receptive and productive vocabulary; walking infants whose parents moved less frequently had larger receptive and productive vocabularies; walking infants who spent more time at a medium distance from the parent had a larger productive vocabulary, but such relation was not found for crawling infants. Finally, Walle (2016) investigated whether and how changes in infants' social context after the onset of walking (i.e., changes in infants following social cues and parent perception of the infant) predict language development over time as a function of walking experience. Findings confirmed that walking experience remained a significant predictor of infant receptive and productive vocabularies. Moreover, the degree to which infants were engaged in joint attention activities with the parents and the extent to which parents perceived the infant as an individual were related to receptive, but not productive, vocabulary size.

Gross Motor Coordination Skills

Only one study (Andalò et al., 2021) has investigated the relationship between motor and language development. They measured four gross motor coordination skills late in the second year of life: *General dynamic coordination*, which indicates a good level of motor control in performing daily motor behaviors; *Balance*, including both static and dynamic abilities to maintain body posture in unstable situations; *Spatial organization*, which enables children to organize movements in areas with spatial hurdles; and *Visual-motor coordination*, which enables children to organize movements in relation to what they see while handling an object. Language outcomes - the children's comprehension and production of nouns, predicates, and spatial vocabulary – were assessed during the third year. General dynamic coordination measured at 18 months of age was found to be longitudinally related to noun production at 24 months; general dynamic coordination at 24 months was longitudinally associated with predicate production at age 30 months but not with noun production. No significant relationships were found between balance or visual-motor coordination and language abilities (Spatial organization was not included in the analysis due to a floor effect found on this measure).

Single Gross Motor Skill Items

Three studies investigated the relationship between gross motor skills and language development using single gross motor skill items. Muluk et al. (2014, 2016) used selected items of both the locomotor and the language scales on the Denver II Developmental Screening Test; the cross-sectional studies involved children aged 5 to 27 months (Muluk et al., 2016) and 33 to 39 months (Muluk et al., 2014). Their results highlighted five significant, concurrent relationships. They were as follows: (a) between "Pull to sit, no head lag " and "Lifts chest with arm support" that measured head control at around 6-7 months and both "Turn to sound" and "Turn to voice" (Muluk et al., 2016); (b) between "Stands holding on" measured at around 12 months and production of a few words other than “mama”/”dada” (Muluk et al., 2016); (c) between "Jump up" measured at around 36 and "Uses plural" and "Comprehends one preposition"; (d) between "Balance on one foot 2 s" measured at around 36 months and "Uses plural" and "Gives first and last name"; and between (e) "Runs" measured at around 36 months and "Names three pictures" (this correlation was negative). Collet et al. (2018) used selected items of the locomotor scale and the two global language scores – receptive and expressive language – on the Bayley Scales of Infant/Toddler Development III. Their longitudinal study measured motor skills at ages seven months (Time 1) and 18 months (Time 2) and language abilities at 36 months. Results highlighted significant, longitudinal relationships between "Controls head while prone: 90 deg" at Time 1 and both receptive and expressive language and between "Sits down with control" at Time 1 and receptive vocabulary.

Short Conclusion

Taken together, these studies show that the attainment of specific gross motor skills, especially of the major motor milestones, predicts later language development, but that the predictive relationships differ by the particular motor and language skills studied. The most robust evidence concerns the longitudinal associations between the onset of unsupported sitting and receptive and productive vocabulary measured at different ages. However, the number of studies that studied sitting is small, and more evidence is still needed to confirm these findings. The gross motor skill most frequently studied was walking, but the results for this skill are not fully consistent. There are several possible explanations for this inconsistency. Firstly, across studies, different types of assessment were used to measure motor and language skills, making it difficult to compare studies. Secondly, many studies had very small sample sizes and lacked sufficient statistical power to detect smaller-sized associations. Thirdly, the use of parental reports in some studies may have resulted in less reliable measures due to parents' subjective views of their child and her competence. Other gross motor milestones and coordination skills have been considered only in one study. Therefore, no conclusion can be drawn regarding their possible effects on language development. Moreover, studies revealing concurrent relationships between specific motor items and language development (Collett et al., 2018; Muluk et al., 2014, 2016) should be treated with caution because these relationships may be attributed to common maturational processes.

Fine Motor Skills

First, we present the main characteristics of the studies focusing on fine motor skills. Then, we present results from studies that measured grasping, manipulation, fine motor coordination skills, and handedness, followed by results from studies that considered single items of fine motor skills. We also included studies on handedness, although it is a genetic trait rather than a motor skill, because handedness is a core characteristic of the child's global action system and affects how children can use their hands to explore. It may therefore influence any potential cascading effect on language acquisition triggered by motor action. Indeed, consistent hand preference is a marker for advanced object manipulation skills (Nelson et al., 2014) which, in turn, could support language acquisition both directly (e.g., leading children to learn about objects' properties and construct categories for word learning; Iverson, 2010, 2021) and indirectly (e.g., stimulating language input from caregivers during children's manipulation; West & Iverson, 2017). We close the section with a short conclusion.

Main Characteristics of the Studies

Eleven studies were included in this section (Table 3). Four studies had a cross-sectional design, six a longitudinal design, and one a mixed design.

Regarding motor measures, handedness was assessed in four studies, and grasping, manipulation, and fine motor coordination skills in the other four separate studies; single items of fine motor skills were used in three studies. Regarding language measures, global receptive vocabulary and productive vocabulary were assessed in most studies (eight), pointing in one study, noun/predicate comprehension and production and spatial vocabulary in one study; single items of language scales were used in two studies. The sample size was smaller than 25 in two studies, between 26 and 50 in four studies, between 51 to 100 in two studies, and over 100 in three studies. Two samples were the comparison groups in studies investigating links between motor and language development in children with and without developmental disorders. The studies were conducted in six countries: the United States (n = 4), France (n = 2), Turkey (n = 2), Italy, The Netherlands, and Taiwan (n = 1 for each of these countries).

Grasping and Manipulation

Three studies (Libertus & Violi, 2016; Oudgenoeg et al., 2015; Wu et al., 2021) investigated potential links between grasping and manipulation skills and language development. Libertus and Violi (2016) assessed the relationship between the growth of grasping ability from 3 to 5 months and receptive vocabulary at 10 and 14 months; their findings did not show any significant association. Oudgenoeg-Paz et al. (2015) assessed whether the amount of time children spent exploring through making combinations of objects at 20 months was predictive of spatial vocabulary at 36 months; at this older age, also, their findings did not show any significant association. Wu et al. (2021) investigated whether there was any cross-sectional link between grasping and object manipulation and receptive and expressive language in toddlers aged 24 to 36 months; they found a significant positive correlation only between object manipulation and expressive language.

Table 3

Main Data Extracted from Studies Included in the Fine Motor Skills Section

Source	N	Study design	Age tested	Motor measurement	Language measurement	Main results
Andalò et al. (2021)	36	MIX	Motor: 18 and 24 m/o Language: 24 and 30 m/o	Object handling, manual dexterity, bilateral coordination (BC), visual-manual integration (GMDS -R 0-2, Eye and hand coordination scale)	Global language ability, receptive/productive noun/predicate and spatial vocabulary (GMDS-R 0-2, GMDS-ER 2-8, MCDI-Italian version, PiNG)	No relationship, although at 24 m/o a combination of BC and GDC (general dynamic coordination) predicted spatial receptive vocabulary.
Cochet (2011)	8	L	15-25 m/o (bi-weekly assessments)	Hand preference for manipulation (battle task and column task)	Global language ability (Brunet-Lézine scale)	No relationship.
Collett et al. (2018)	158	L	Motor: 7 and 18 m/o Language: 3 y/o	BSID, FM scale (selected items)	Global receptive and productive language (BSID)	At 7 m/o: no relationship. At 18 m/o: "Transitional grasping" was related to receptive language, and "Imitates stroke: circular" was related to expressive language.
Esseily et al. (2010)	22	CS	14 m/o	Hand preference for grasping	Pointing (frequency) Global receptive and productive vocabulary (MCDI-French version)	No relationship.
Gonzales et al. (2020)	90	L	Motor: 18-24 m/o (monthly assessments) Language: 5 y/o	Hand preference for manipulation (RDBM test)	Auditory comprehension and expressive communication (PLS-5)	Children showing a stronger right-hand preference had higher language abilities (especially receptive vocabulary) than children with a left-hand preference or moderate left-hand use.

Libertus & Violi (2016)	29	L	Motor: from 3-5 m/o (8 weekly assessments) Language: 10 and 14 m/o	Grasping duration	Global receptive vocabulary (MCDI)	No relationship.
Muluk et al. (2014)	160	CS	3 y/o	DDST-II, FM scale (selected items)	DDST-II, Language scale (selected items)	"Imitates bridge" was related to "Uses plural, "Names pictures", "Gives first and last name", and "Knows one adjective".
Muluk et al. (2016)	505 Group 1: 6 m/o (range 5 to 7, n=162) Group 2: 12 m/o (range 11 to 13, n=127) Group 3: 18 m/o (range 17 to 19, n=101) Group 4: 24 m/o (range 23 to 27, n=115)	CS	6,12,18,24 m/o	DDST-II, FM scale (selected items)	DDST-II, Language scale (selected items)	No relationship.
Nelson et al. (2014)	38	L	Motor: 6-14 m/o and 18-24 m/o (monthly assessments) Language: 24 m/o	Hand preference for manipulation (RDBM test)	Global language ability (BSID-III)	Children with a consistent right-hand preference between both 6-14 m/o and 18-24 m/o scored higher on the language measure at 24 m/o.
Oudgenoeg-Paz et al. (2015)	59 First cohort=8 Second cohort=31	L	Motor: 20 m/o Language: 36 m/o	Object exploration (observation)	Spatial productive vocabulary (specific test)	No relationship.

Wu et al.(2021)	38	CS	Between 24 and 38 m/o	Object manipulation, Grasping, and visual-motor integration (PDMS-II)	Global receptive and productive language (MSEL)	Object manipulation and visual-motor integration were positively correlated to productive language.

Note. BSID, Bayley Scales of Infant Development; CR, cross-sectional; DDST, Denver Developmental Screening Test; FM, Fine Motor; GMDS, Griffiths' Mental Development Scales; L, longitudinal; MCDI, MacArthur-Bates Communicative Development Inventories; MSEL, Mullen Scales of Early Learning; MIX, mixed; m/o, months old; PDMS, Peabody Developmental Motor Scales; PiNG, Picture Naming Game; PLS-5, Preschool Language Scales-5; RDBM, Role-differentiated Bimanual Manipulation; y/o, years old.

Fine Motor Coordination Skills

Two studies (Andalò et al., 2022; Wu et al., 2021) investigated potential links between fine-motor coordination skills and language development. Andalò et al. (2022) measured four fine motor coordination skills late in the second year: *Object handling*, which allows children to manipulate and handle objects properly, *Manual dexterity*, which develops from fine and accurate object handling and enables children, for example, to build a tower of blocks, *Bilateral coordination*, which indicates children's ability to use both hands with a complementary differentiation of hand function and *Visual-manual integration*, which allows children to carry out complex tasks in which perceptual and manual motor skills need to be integrated, such as drawing. The language measures -- the children's comprehension and production of nouns, predicates, and spatial vocabulary -- were assessed during the third year. No significant associations were found between manual dexterity, visual-manual integration and/or bilateral coordination, and language abilities (object handling was not included in the analyses due to a ceiling effect). Only a combination of fine and gross motor coordination skills – bilateral coordination and general dynamic coordination – at 24 months predicted receptive spatial vocabulary at 30 months. The findings on visual-motor integration are not consistent with those of Wu et al. (2021), who found that visual-motor integration was positively correlated with expressive language in children aged 24 to 36 months. No significant associations were found between object manipulation and grasping on the one hand and language abilities on the other.

Handedness

Four studies investigated the relationship between handedness and language development. Handedness was measured for grasping objects (Esseily et al., 2011), object-directed actions (Cochet, 2011), and role-differentiated bimanual manipulation (RDBM) (Gonzales et al., 2020; Nelson et al., 2014). RDBM is the complementary use of hands with distinct roles (e.g., one hand holds the object for the other hand's actions) (Nelson et al., 2013). Nelson et al. (2014) assessed handedness at monthly intervals from 6 to 14 months and again from 18 to 24 months, and language skills at 24 months (as a global score on the Bayley-III language scale). They found that children with a consistent right-hand preference both at infant and toddler visits scored higher on the language measure at 24 months. Gonzalez and colleagues (2020) investigated predictive relationships between handedness measured from 18 to 24 months and receptive and expressive language at five years. Their findings indicated that children with more consistent right-handedness in infancy had higher language abilities in childhood (especially receptive vocabulary) than children with a left-hand preference or moderate left-hand use. On the contrary, Esseily et al. (2010) found no significant relationship between handedness and frequency of pointing and receptive and productive vocabularies in 14-month-old infants. Also, Cochet (2011), who assessed both handedness and language (a global score on the Brunet-Lézine scale) bi-monthly between 15 and 25 months, did not find any significant association at any age point considered.

Single Fine Motor Skill Items

The three studies that examined the relationships between single gross motor skill items and language ability also examined the relationships between single fine motor skill items and language ability (Collett et al., 2018; Muluk et al., 2014, 2016). The results showed significant relationships only in older children. In particular, “Transitional grasp” (an advanced grasping skill) and "Imitates stroke: circular" (visual-motor integration in drawing) at 18 months were found to be associated longitudinally with receptive and expressive language at 36 months (Collett et al., 2018). “Imitates bridge” (visual-manual integration in drawing) was found concurrently associated with "Uses plural", "Names pictures", "Gives first and last name", and "Knows one adjective" at three years (Muluk et al., 2014).

Short Conclusion

The studies included in this section vary greatly in study design, motor and language skills considered, and age of measurement. This makes it difficult to compare them and draw any conclusion. Taken together, their findings do not seem to support the idea that early-age fine motor skills could influence language development. Evidence from studies assessing handedness and fine motor skills at older ages –that is, across the end of the second year and the third year – suggests a possible link between more consistent right-handedness and fine motor coordination skills and later language abilities. However, the number of studies that focused on language abilities in relation to fine motor skills is small, and the results should, therefore, be interpreted with caution. Furthermore, some concurrent associations between motor and language skills highlighted in older children could be spurious and reflect general maturation.

Discussion

The present review aimed to summarize studies focusing on the links between motor and language development. According to a developmental cascades perspective (Adolph & Hoch, 2019; Iverson, 2021; Oakes & Rakison, 2019), the mastery of specific motor skills activates cascades of events that change how children act in their daily world and how people interact with them; these changes become learning opportunities which could scaffold language acquisition in different ways. The studies we reviewed in this article suggest the presence of three possible cascading effects on the language developmental domain. They are activated, respectively, by improvement in postural control, attainment of walking, and advanced manipulation experience. However, more consistent evidence was found only for a cascading effect triggered by the attainment of walking.

Possible Cascading Effects of Advances in Motor Development on Language Acquisition

A first potential cascading effect on communication and language domain is enabled by the achievement of postural control that starts with head control, increases with the attainment of unsupported sitting, and ends with an upright position. Being able to control the head and the trunk changes the infant’s point of view, providing new perceptual experiences and, consequently, the information they receive from the environment. Furthermore, it allows infants intentionally to turn their gaze wherever they want, supporting face-to-face interactions with their caregivers. The most consistent evidence is on unsupported sitting and reveals that more growth in the duration of independent sitting measured between 3 and 5 months of age predicts a larger receptive vocabulary at ten months (Libertus & Violi, 2016). Moreover, an earlier age of sitting is significantly related to the growth in productive vocabulary measured between 16 and 28 months (Oudgenoeg et al., 2012) and marginally significantly to productive spatial vocabulary measured at 36 months (Oudgenoeg et al., 2015). In these studies, longitudinal designs and robust statistics produced solid evidence. Their conclusions, however, must be viewed with caution because it is a small number of studies and they measured language outcomes differently, making valid comparisons problematic. The role of other postural milestones, such as head control and standing, has only been marginally investigated. Head control was found to be concurrently associated with turning to sound and voice (Muluk et al., 2016). Indeed, “turning” is a motor skill more than language ability. However, intentional turning gaze to a voice leads to joint-attention behaviors, which, in turn, can scaffold communicative exchanges between child and caregivers. Note that these relationships are concurrent and do not indicate a predictive role of head control for later language abilities. On the other hand, Collett et al. (2018) found longitudinal relationships between head control measured at seven months and language abilities at 36 months. Taken together, the results from Collett et al. (2018) and Muluk et al. (2016) offer preliminary evidence of a link between acquiring head control and later language development. Further longitudinal studies are needed to support these findings, or not, and deepen our understanding of any possible cascading effects of head control on later language abilities, especially in the short and medium-term, before the experience with unsupported sitting starts to change the infant’s interaction with the environment.

Standing has been investigated in only two studies, which are hardly comparable due to different study designs and measures, although infants were assessed at the same age (around 12 months). Muluk et al. (2016) found concurrent associations between standing (measured using the items "Stands holding on" and "Stands alone 10 seconds" of the DDTS II) and productive language (measured using the items "Mama/dada specific" and "4 words other than mama/dada" on DDTS II). Bradshow et al. (2018) found that standers were not statistically distinguished from both pre-walkers and walkers on communicative gestures and sounds and word production. Standing might be further longitudinally explored as an intermediate stage in the transition to walking in order to understand better the role played by postural and/or locomotor aspects in the relationships between walking and language abilities found by many other studies.

A second possible cascading effect on language acquisition is enabled by the attainment of walking. This milestone creates the conditions for a cascade of multidirectional effects influencing the infant's language environment and language acquisition (Iverson, 2021). The onset of self-locomotion is “one of the major life transitions in early development and involves a pervasive set of changes in perception, spatial cognition, and social and emotional development” (Campos et al., 2000, p. 149). Indeed, studies included in this review highlighted that walking experience, more than self-locomotion *per se,* can play a role in scaffolding language development. Self-locomotion usually starts with crawling, but the only study focusing on crawling and any possible concurrent associations with vocalization did not find any significant results (Berger et al., 2017). On the other hand, studies comparing crawlers and walkers at the same age revealed statistically significant relationships only between walking *status* and language outcomes (e.g., He et al., 2015; Walle, 2016; Walle & Campos, 2014; West et al., 2019). The effects of the walking experience on language development were confirmed by longitudinal studies (Lüke et al., 2019; Oudgenoeg-paz et al., 2012, 2015). The authors offered different possible explanations for the effects of walking on language development. For Oudgenoeg-Paz et al. (2015, 2016), more coordinated and efficient movements may result in a greater exploration of the environment and enhanced exposure to novel objects. And indeed, exploration through self-locomotion has been found to mediate the relationship between walking onset and spatial vocabulary measured at 36 months. For Karasik et al. (2014) and West & Iverson (2021), hands-free locomotion may facilitate communicative exchanges where hands play a main role, such as pointing and object bids which, in turn, may increase opportunities for labeling offered by caregivers. Walle (2016) and Walle & Campos (2014) argue that independent and free moving may alter parents’ speech because the child is perceived to be a more competent partner. Yingling (1981) suggested that the upright position enlarges infant breathing, fostering the functioning of the diaphragm, which, in turn, may facilitate vocalization. These explanations led He et al. (2015) to define walking as an “epigenetic event” (p. 285) that significantly affects a broad range of psychological processes, including language development. However, the relationship between walking and language abilities, which is strongest around the onset of walking, seems to become weaker or disappear at older ages (Lüke et al., 2019; Oudgenoeg-Paz et al., 2015, 2016). Initially, walking onset is crucial as it facilitates new ways of interacting with the environment, which is relevant for language acquisition. At a later stage, the initial advantage of progressive motor development disappears because all children have acquired the motor skills concerned and have built up much of the sensorimotor cognition on which further language learning, through input, can develop.

A third potential cascading effect on language could be triggered by advanced fine motor skills such as advanced manipulation and fine motor coordination skills. But the results of studies focusing on this potential link between motor and language development are inconsistent, and the evidence is relatively weak. Fine motor skills allow children to obtain and explore objects, thereby gaining more differentiated knowledge of them by noting their specific features and functions (Lederman & Klatzy, 2009). In this sense, the embodied sensorimotor cognitions that children learn while exploring objects may facilitate the attribution of more specific meaning to object features and functionalities, an important process required, among other processes, for learning words (Iverson, 2010). Although fine motor skills occur early in life, studies investigating grasping and manipulation in the first months did not find any significant relationship with later language abilities. However, several studies that focused on later, advanced fine motor skills found significant concurrent and longitudinal links (Andalò et al., 2021; Muluk et al., 2014). In addition, studies on handedness partially support the idea that more controlled and efficient manipulation (especially in children with right-hand preference) could play a role in language advances in 24-month-old children and preschoolers (Gonzalez et al., 2020; Nelson et al., 2014). However, the studies are not properly comparable because of the differences in the types and ages of motor and language assessments used. Taken together, the results suggest that fine motor skills are likely to have a later impact on language development and that this impact narrows down to specific language skills such as spatial vocabulary (Andalò et al., 2021) and Body-Object Interaction vocabulary (i.e., words with high levels of body-object interaction; Suggate & Stoeger, 2014). Further studies are needed to explore whether fine motor skills could affect other specific language abilities that were not measured in previous studies at early ages (e.g., communicative gestures) and to get a better understanding of the effects of specific fine motor skills on particular language skills that could at older ages be affected by the fine motor experience, such as vocabulary related to object functions.

Finally, it is important to note that the three possible cascading effects from the motor to the language developmental domains cannot be viewed as separate but rather as closely interrelated. Being able to sit or maintain an upright position without support and walking instead of crawling not only provides different visual experiences and scaffolds face-to-face behaviors (e.g., joint attention, pointing toward and naming objects) but also frees hands for manual exploration of objects. Thanks to their hands being free, children can engage in deep exploration of objects by holding, manipulating, and rotating them to learn about their features, which is fundamental for constructing basic categories and subsequent word learning (Iverson, 2021). Furthermore, infants' object manipulation can elicit caregivers' language input, as West and Iverson (2017) highlighted. Walking experience (the second cascade) also dramatically changes infants' experiences in their wider environment. Walking infants can explore the environment more efficiently, reach and catch objects easily, and initiate social interaction with their caregivers by sharing objects and attention to objects. Mothers of walkers are more likely than mothers of crawlers to respond to moving bids with language encouraging children to act on objects (Karasik et al., 2014), which may help to activate the third cascade.

"Temporal Issues" for Investigating Links Between Motor and Language Development

Discussion of the possible cascading effects of advances in motor skills on language abilities must not focus only on which motor skills trigger which potential language acquisition or what mechanisms characterize links between motor and language development. They must also address how these links change over developmental time. We point out two "temporal issues".

The first issue concerns when motor and language skills are assessed. Mastering a fundamental motor skill at a given time changes what a child can or cannot do and creates new opportunities that can activate cascading effects on later experiences: motor development enables subsequent social and cognitive learning, including language. Thus, studies using longitudinal design capture possible cascading effects better, arguably, than those using a cross-sectional design. They may also offer more robust evidence of possible effects of motor advances on later language development. However, a longitudinal research design, rather than cross-sectional, is not enough. The grain and timing of measurements are crucial factors in capturing the mechanisms underlying the change processes and conditions that -- across developmental domains -- are likely to promote the emergence of change in development. Microgenetic designs (Lavelli et al., 2005/2008) with an elevated density of measurements in multiple domains (including direct measurements of the mechanisms hypothesized to be involved, such as exploration and caregiver’s language input for language acquisition) within a developmental transition period are needed for better capture of possible cascading processes.

The second issue relates to the length of the assessment. The links between motor and language development are not stable but change over time. Early links between motor skills and language abilities across the first and second years of life decrease and weaken over developmental time. Longitudinal studies that measured sitting and walking, for instance, described a developmental trend in which the onset of motor milestones predicts language abilities in the short to medium term, but the link becomes weaker in the medium term and disappears in the long term. Future studies are needed to investigate whether this trend may characterize other possible links between specific motor skills and specific language abilities.

Temporal aspects of the relationship between motor and language development are still little investigated. Future studies should explore the short, medium, and long-term effects of motor milestones so far considered only marginally, such as head control and standing. They should also focus on other temporal links between the achievement of motor skills and the achievement of language abilities, especially during major developmental transitions in which the emergence of new abilities changes the infant's experience in the environment and their opportunities to explore it.

The Links Between Motor Skills and Specific Language Abilities

The final issue to be addressed concerns language measurement. To investigate the "specific and meaning-intrinsic nature" of the links between motor and language skills (Oudgenoeg et al., 2016, p. 2), it is essential to choose, deliberately, which motor and which language abilities to assess at which ages, possibly following hypotheses about the links.

Indeed, specific motor skills could activate particular developmental cascades, which, in turn, could affect specific language abilities. Most studies that involved infants and toddlers have measured receptive and productive vocabulary. Vocabulary size is a good measure of language development and can be used to investigate possible cascading effects of motor development on the language domain. For instance, walking may facilitate communicative exchanges and object bids between infants and their caregivers, which may increase opportunities for labeling. However, evidence from the studies conducted with children across the third year, when most children have already acquired substantial basic vocabulary knowledge, indicates that it is important to focus on specific language skills that could be affected by the motor experience, rather than on general language skills. These specific language skills include predicates of motor actions (Andalò et al., 2021) and spatial vocabulary, consisting of locative adverbs and prepositions, and adjectives related to perception-action experiences (Oudgenoeg-Paz et al., 2015, 2016). Furthermore, to deepen our understanding of the links between motor and language development, it will be useful to identify not only which language abilities can be related to motor skills but also which language abilities are not related (Oudgenoeg-Paz et al., 2016). The latter can contribute to differentiating motor-language links rooted in general maturation from specific links based on particular motor cascading effects on language. and the nature of perception-action experiences, as suggested by the embodied cognition and dynamic systems approaches to development.

Conclusion

Responding to the recent growth in the number of scientific publications discussing links between motor and language skills, this systematic review aimed to extend and deepen the evidence examined by previous reviews. We summarized studies investigating the effects of specific motor skills on language development, highlighted motor-language cascading pathways, and explored how these cross-domain pathways develop over time. The links between motor and language development shown by the studies reviewed suggest the presence of three possible cascading effects of advances in motor development on language acquisition. These possible effects are enabled by the attainment of specific motor skills – postural control, walking – and advanced fine motor skills. The link between movement and language supports the view that children develop through constant dynamic interaction with their environment. Indeed, infants and toddlers interact constantly with their environment, which, in turn, provides them with feedback on their actions and communications and new information, which then further guides their actions and advances development. As Iverson (2021, p. 233) notes: "Action and movement support environmentally mediated opportunities for communication and learning that are critical for the development of language." However, it is clear from this review that more work is required to understand better several facets of this dynamic relationship.

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CAPITOLO 2

Exploring the links between early locomotion experience and language acquisition

Introduction

Motor development and language development have historically been viewed as independent domains. Early child-language researchers (e.g., Lenneberg, 1967) considered language development a specific developmental process and argued that it is different (and separated) from other developmental processes such as motor development.

However, in the last decades, many researchers have studied (and continue studying) the co-development of motor and language skills showing that these two domains are more strictly and dynamically interrelated than previously thought (e.g., Thelen, 1995; Thelen & Smith, 1994). This dynamic perspective assumes that motor advances are neither necessary nor sufficient for language development, but “normally participatory” (Iverson, 2010, p. 255); in other words, motor advances open new opportunities for active interactions with environment and people, that *can* affect language development. Indeed, in everyday life, when children move in the environment, they interact with people and objects, making experiences and gathering information about them; doing so, they trigger many learning opportunities, including language acquisition. For instance, when an infant starts self-locomotion and freely moves in a room, she can stop and hide under the table, having a direct experience of 'under'; she probably receives specific verbal input from caregivers, such as “Where did you hide? I don’t see you anymore! …Ah, here you are! Under the table”. Moreover, self-locomotion leads infants to reach and grasp objects which were previously out of their reach, and their actions can trigger communication exchanges with caregivers. When an infant catches a ball, it is likely that caregivers comment on the event with sentences such as “What a nice ball! It is red, do you see? Come on, throw it at me!”. These perception-action experiences, combined with parents' input about the infant’s experiences, may scaffold the matching between the experienced-concepts (“hiding”, “under”, “red ball”, and “throw” in the examples mentioned above) and the corresponding verbal labels, promoting infants' language acquisition.

The Role of Self-locomotion in Language Development: The Contribution of Walking

The onset of self-locomotion is “one of the major life transitions in early development and involves a pervasive set of changes in perception, spatial cognition, and social and emotional development” (Campos et al., 2000, p. 149). Self-locomotion leads to important developmental consequences in infants' behaviors, such as increased abilities to shift and join attention, increased intentionality and goal-directed behaviors, richer social interactions, and easier/more frequent opportunities to share an object with subsequent object-labeling offered by caregivers (Bertenthal et al., 1984; Campos et al. 1997, 2000). Indeed, studies on the relationship between the acquisition of self-locomotion and language development focused on walking experience more than self-locomotion *per se*, highlighting both cross-sectional and longitudinal evidence (e.g., He et al., 2015; Lüke et al., 2019; Oudgenoeg-paz et al., 2012, 2015; Walle, 2016; Walle & Campos, 2014; West et al., 2019). Authors offered different, possible explanations for the effects of walking on language development: (1) more coordinated and efficient movements may result in greater exploration of the environment; indeed, exploration through self-locomotion has been found to mediate the relationship between walking onset and spatial vocabulary measured at 36 months (Oudgenoeg-Paz et al., 2015); (2) the upright position enlarges infant breathing fostering the functioning of the diaphragm, which, in turn, may facilitate vocalization production (Iverson, 2010); (3) when infants move in an upright position, compared to a prone position, are more like to hear verbal input from their caregivers (Schneider & Iverson, 2021); (4) hands-free locomotion may facilitate communicative exchanges in which hands play a main role, such as objects bids; indeed, it was found that infants’ locomotor status (crawling *versus* walking) affects the way they share objects with their mothers, which in turn elicits different verbal responses from mothers: mothers of walking infants, compared to mothers of crawling infants, used more action requests (such as ”Open it” or ”Bring to me”) than affirmations or descriptions (such as ”Thank you” or "That's a nice red box”) during objects sharing (Karasik et al., 2014); (5) independent and free moving may alter parents’ communication in accordance with what is perceived to be a more competent partner (Walle, 2016); indeed, it was found that parents of walkers, compared to parents of crawlers, offer a greater amount of input (Walle & Campos, 2014) and have more opportunities to respond contingently to their infants. West and Iverson (2021) found that after learning to walk, infants increased coordinated gestures and vocalizations with locomotion (e.g., by walking to a caregiver and showing off a ball); consequently, caregivers had more possibilities to respond contingently to their infants either with requests (e.g., "What did you find?") or comments (e.g., "That's a very nice ball!") or providing information about the object (e.g., “This is a ball! A small ball”) (Schneider & Iverson, 2021; West & Iverson, 2021). Few studies have also explored individual mechanisms, factors and/or mediators that may help explain the relationships between walking and language development. Oudgenoeg-Paz et al. (2015, 2016) found that exploration through self-locomotion partially mediated the relationship between age of walking onset and spatial vocabulary at 36 months and later. Walle and Campos (2014) considered social-environmental aspects such as infants' proximity to the parent, and the amount of both parent and infant movements during a free play session, and explored whether they were related to infants' language development as a function of locomotor status (crawling *versus* walking). Findings showed that: (1) walking infants who received more language input from the parent had larger receptive and productive vocabularies, whereas language input was unrelated to receptive and productive vocabularies for crawling infants; (2) walking infants whose parents moved less frequently had larger receptive and productive vocabularies; (3) walking infants who spent more time at a medium distance from the parent had a larger productive vocabulary, but no such relation was found for crawling infants.

In summary, walking has both postural and locomotor aspects which could support language acquisition. The erected torso and the head –free to move and look forward–provide wide and diverse visual experiences and encourage face-to-face exchanges with caregivers. Furthermore, this posture facilitates children to freely use their hands both for manual (and visual) exploration of objects (Soska et al., 2010) and for producing communicative gestures such as pointing, that was found associated to language comprehension and production, concurrently and longitudinally (for a meta-analysis, see Colonnesi et al., 2010). Finally, walking is a very effective and efficient way to move in the environment. It offers the possibility to combine more than one action, for example, moving and taking/offering an object to the parent, that is, initiating social bids, which are fundamental contexts of language learning.

However, it is essential to note that infants do not start to move in the environment by walking but a few months earlier, with the acquisition of crawling.

The Onset of Crawling and Its Developmental Role

Crawling represents the first attempt at purposeful self-locomotion (Gallahue et al., 2012). It usually appears around 7-8,5 months of age (Lyytinen et al., 2001; Viholainen et al., 2002, 2006) and develops in an age range from 5 to 11 months (Adolph & Robinson, 2015). At first, in a prone position, infants start to move and may reach objects not far away, raising their head and chest off the floor. The legs are usually not used in the early attempts of crawling, but the result is the first, sliding form of self-locomotion through the space. Creeping evolves from crawling and offers a highly efficient form of self-locomotion in which infants use legs and arms in opposition to one another. The first attempts of creeping are usually characterized by movements of only one limb at a time. Still, movements become synchronous and more rapid in a short time, leading infants to cover large distances and, if they want, reach and catch distal objects. Crawling[1], but especially creeping, offers infants and toddlers all benefits of independent mobility. Crawlers can move through the environment exploring new surfaces and places; they also can navigate obstacles and control their proximity to objects and people (Campos et al. 2000; Gibson, 1988). Adolph and Tamis-LeMonda (2014) have highlighted that skilled crawlers can achieve an "adult-like precision" in moving through space. For example, experienced 12-month-old crawlers calibrate possibilities for crawling up and down slopes and avoid obstacles with near-perfect accuracy (Adolph, 1997; Adolph et al., 2008; Kretch & Adolph, 2013); an expert crawler can simultaneously move through the space and direct attention to objects and people with whom she interacts.

[1] In line with the literature on the relationships between motor and language development, starting from this point of the text we will use the term "crawling" to indicate both crawling proper and (especially) creeping.

However, crawling allows self-locomotion in specific postural and motor conditions. When infants crawl, their gaze is usually downward, forward the floor, the field of view is limited (Kretch et al., 2014), and they have to hyperextend their neck if they want to look at things/faces/events above the highest point in their field of view. The hands are involved in locomotion, and infants cannot wholly use them to communicate by gesture or manage objects. These features might slow down the process of language acquisition when crawling is maintained as the main form of self-locomotion even when infants usually attain the independent walking.

Links Between Crawling and Language Development

As noted above, most studies on the links between self-locomotion and language development focused on walking. Only a few studies focused on crawling. Moreover, in most of them, crawling is compared to walking to highlight differences in developmental trajectories of language between crawlers and walkers.

Some studies compared the effects of crawling *versus* walking status on communicative gestures. Clearfield (2011) found that walking infants used gestures (deictic gestures) significantly more than crawling age-mates. In contrast, Bradshow et al. (2018) and Karasik et al. (2014) did not find any significant difference in communicative gestures between the two groups of infants. Other studies compared infants' receptive and productive vocabularies before and around the age infants start walking, but the results are, again, inconsistent. Some of them (He et al., 2015; Walle & Campos, 2014, 2016; West et al., 2019) found that the onset of walking was related to a significant increase in receptive and productive vocabularies; in contrast, Moore et al. (2019) and Karasik et al. (2014) did not find any significant difference in vocabulary size between walkers and crawlers.

One study (Berger et al., 2017) examined the link between crawling and the production of vocalizations, but its focus was on infants' allocation of attentional resources over the transition to crawling rather than on the contribution of self-locomotion to language acquisition. The authors analysed the trajectories of concurrent motor and vocal behaviors around 8 months at four key time points over the transition to crawling: 2 weeks pre-crawling, crawling onset, and 2- and 4 weeks post-crawling onset. Results revealed that vocalizations and crawling were significantly unlikely to co-occur at the session marking the crawling onset. The authors argued that when mastering a novel skill (such as the acquisition of crawling), infants may have difficulty allocating attention to more than one task.

No evidence that crawling could play a role in infant's language development comes from these studies. On the contrary, some findings have shown that the onset of crawling may alter parents’ communication, although in different ways than walking (Campos et al., 1992; Zumbahlen & Crawley, 1997). Compared to mothers of pre-locomotor infants, mothers of crawlers increase their use of verbal prohibitions and use their voice predominantly to convey prohibitions. This is because a crawler ends up in inappropriate or dangerous situations: the infant wants to crawl toward the steep staircase, or touch the electrical outlet, and caregivers needs to thwart these behaviors. Conflict is inevitable in these situations, so it’s no wonder that parental prohibitions, including the word “no”, become much more common when the infant starts self-locomotion.

However, many aspects of the crawling experience and its potential effects on infant's language development have not yet been investigated. Most studies did not consider crawling as the first form of self-locomotion but, rather, as the motor stage that precedes the acquisition of walking, in other words, as a kind of "less-skilled ability" of locomotion compared to walking. Nevertheless, the onset of crawling, rather than walking, dramatically changes the infants' everyday life; it leads them to pass from a stationary condition to a dynamic one, suddenly multiplying the opportunities to interact with the environment and people, which is fundamental to language acquisition. On the other hand, the typical posture of crawling (with the head oriented towards the floor) limits the field of view; this limitation, in turn, might affect the interaction with people, for instance making it more difficult to follow the caregiver’s gaze and joint the attention. Finally, the only study that focused on crawling (Berger et al., 2017) considered the period around the onset of the motor milestone; possible longitudinal effects of crawling on communication and language development have still to be explored.

The Present Study

Several issues regarding the potential role of self-locomotion in language development are still open. The present study attempts to investigate some of them with a focus on crawling. Study 1 explores possible links between self-locomotion (crawling first and walking later) and language development from 8 to 16 months. Study 2 extends previous studies by examining whether the infant's locomotor status (crawling vs non-crawling infants at 8 months, walkers vs crawlers at 12 months, and expert walkers vs novel walkers at 16 months) may affect parents' verbal input in a sample of Italian families; then, Study 2 explores possible predictive relationships between infants' locomotor status and language abilities accounting for individual and social factors (parents' verbal input).

Study 1

In Study 1, we used a longitudinal design to follow a group of infants between 8 and 16 months, an age range within which crawling generally emerges and develops until it is replaced by walking. We first tested the hypothesis that crawling could contribute to language development inasmuch, being the first form of self-locomotion, triggers many learning opportunities that could promote language acquisition. In particular, we expect that infants who have a high performance in crawling at 8 months (that is the average age of crawling onset; Lyytinen et al., 2001; Viholainen et al., 2002, 2006), compared with infants with lower performance, have: (a) a broader repertoire of communicative behaviors at 8 months; (b) a broader repertoire of communicative behaviors and a richer receptive vocabulary at 12 months. Furthermore, we expected that the effect of crawling on language abilities decreases/disappears when crawling is replaced by walking, which has a documented, significant impact on language acquisition (e.g., He et al., 2015; Walle & Campos, 2014; West et al., 2019). Thus, we tested whether infants who improve their locomotion skills and start walking at 12 months (that is the average age of walking onset; Lyytinen et al., 2001; Viholainen et al., 2002, 2006), compared with infants who maintain crawling as main form of self-locomotion, have: (a) a broader repertoire of communicative behaviors and a richer receptive vocabulary at 12 months; (b) a richer receptive and productive vocabulary at 16 months.

Method

Participants

Fifty-nine typically developing Italian infants (32 females) and their primary caregivers were enrolled in this study that is part of a larger longitudinal research aimed at exploring links between motor and language development in infancy. The recruitment involved educational, social and health services in northeast and central Italy; we also used social network posts and parenting websites. Three families dropped out in the early stages of the research; five infants were excluded *ex-post* due to exposure to other languages (Bulgarian, Hungarian, Polish, Russian, and Spanish); another infant was excluded *ex-post* because, in the pre-walking phase, she did not crawl with knees or feet and hands, but only scooted forward on her bottom and directly moved on to walk. The final sample consisted of 50 monolingual participants (26 girls). All infants had gestational age beyond 37 weeks. According to their caregivers, none of them had known developmental disabilities or delays or vision or hearing problems at the time of recruitment. Twenty-nine infants (58%) were firstborn, the others second, third or fourth born. On average, infants were being raised by parents with medium socioeconomic status (SES) that was coded by combining both parents’ educational and professional status (Pierrehumbert et al., 2003). Sociodemographic characteristics of infants and parents are reported in Table 1. Parental informed consent was obtained according to the procedure approved by the Ethical Committee of the Department of Human Sciences, University of Verona, in February 2019 (Cod. 2019_02).

Procedure and Measures

At the beginning of the study, all families completed a questionnaire concerning information on the infant and her health state, and parents. We also gathered information about exposure to other languages, the main features of the house and some family's motor and language habits that were not considered in this study. Starting around 4 months and up to 16 months, all families were visited at home by the first author every four months. The visits were organized at the most convenient time for families (either in the morning or in the afternoon).

Table 1

Infants' and Parents' Characteristics

Characteristics	*M (SD)*	*Range*
Infants		
Gestational age (weeks)	39.83 (.89)	37-42
Birth weight (Kg)	3.28 (.48)	2.17-4.39
Parents		
Maternal age (years)	34.38 (4.19)	25-45
Maternal education (years)	16.98 (2.53)	13-24
Paternal age (years)	37.96 (5.33)	29-54
Paternal education (years)	14.34 (2.76)	8-18
Family		
Socioeconomic status	2.69 (.61)	1.5-4

During the visit, infants and parents were videotaped in daily play activities for approximately 10 minutes; when the visit in person was impossible[2], the researcher scheduled a video call and asked parents to make the video by themselves. In this study, videos were only used to check the infant's language exposure and motor development about crawling performance at 8 months and locomotion performance (crawling and walking) at 12 months. At 4, 8, 12, and 16 months of the infant's age, parents completed a questionnaire to assess the infant's motor development at the time of the scheduled visits or in the previous/later days; at 8, 12 and 16 months they also completed a questionnaire to assess the infant's language development. We tracked the exact day of filling in the questionnaires to check that the age of the assessment was within a range of +/- 3 weeks. Only in a few cases parents filled in the questionnaires within a range of +/- 4 weeks. All questionnaires were collected in a Baby Diary provided to the

[2] Since data collection started in 2019, some in-person visits were not carried out due to Covid-19 pandemic restrictions.

family at the beginning of the study. The Baby Diary was available in digital and paper format; each family could choose which form to use. In the Baby Diary, we also inserted a section called 'At which age?' in which parents tracked the onset of six main postural and motor milestones: head control, rolling, sitting, crawling, standing, and walking. For each milestone, we provided a brief description (inspired by Frankenburg et al., 1992, and Bodnarchuk & Eaton, 2004; see Table 2).

Table 2

Description of Postural and Motor Milestones

Motor milestone	*Description*
Head control	The infant, placed on her stomach on a flat surface (carpet or bed), lifts her head so that her face makes an approximately 45-degree angle with the surface for at least several seconds.
Rolling	The infant rolls from back to stomach and/or from stomach to back without an adult's help.
Sitting	The infant sits alone (not propped with pillows or a chair) without using hands for support for at least 45 s.
Crawling	The infant mainly uses hands and knees or hands and feet to move herself in the environment.
Standing	After using furniture or another support to pull up to a standing position, the infant takes both hands off the support and balances for at least 3 s without help.
Walking	The infant walks through a room without support from a parent or furniture; the infant uses walking as the main form of self-locomotion.

Motor Measures

We used two motor measures: (1) crawling performance at 8 months (M = 8.37, SD = .39); (2) locomotion performance at 12 months (M = 12.36; SD = .43).

Both measures were derived from *The Early Motor Questionnaire-EMQ* (Libertus & Landa, 2013). The EMQ is a parent-report questionnaire in which parents answer simple questions about their child's motor skills in an everyday context. The instrument is organized into 3 sections: gross motor skills (49 items), fine motor skills (48 items), and perception-action integration skills (31 items). The items included in the EMQ describe motor behaviors typically emerging within the first 2 years of life. Parents rate each motor behavior on a 5-point scale ranging from -2 (sure child does not show the behavior described) to + 2 (sure child shows the behavior); parents use the 0-score when they are not sure if their child shows or not the behavior described. The EMQ shows good validity compared to standardized experimenter-administered motor assessment (for details on the tool's construction and validity, see Libertus & Landa, 2013). Only the gross-motor section has been used in the present study.

To test the first hypothesis, a score of crawling performance, ranging from -6 to +6, was calculated by using the three items regarding crawling in the gross-motor section of the EMQ: (1) *When placed into a sitting position on the floor, your child is able to shift into a crawling position and try to crawl forward*; (2) *When placed into a crawling position resting on hands and knees, your child will crawl forward for a few steps (3-5)*; (3) *When placed in front of a flight of stairs, your child is able to creep up the stairs independently*. Subsequently, we divided the sample into three groups based on the infant's crawling performance: (1) the first group (Low-performance group, N = 16) performed between -6 and -3 scores, which means that infants did not start crawling; (2) the second group (Medium-performance group, N = 13) performed between -2 and + 1 scores, which means that infants were novel crawlers, had just learned to crawl and started to use it daily; (3) the third group (High-performance group, N = 21) performed between 2 and 6 scores, which means that infants were expert crawlers, used crawling as the main form of self-locomotion and were able to use it even in specific space such as stairs. This grouping is in line with a theoretical model in which the process of motor development reveals itself primarily through gradual changes in motor behaviors over time (Gallahue et al., 2012). These 'changes' involve both process (form of movements) and product (performance). With regards to performance, three stages can be observed: (1) initial stage (low performance), in which movement is characterized by missing or improperly sequenced parts, restricted or exaggerated use of the body, and poor coordination; (2) emerging elementary stage (medium performance), in which patterns of movement are still generally restricted or exaggerated, although better coordinated; (3) proficient stage (high performance), characterized by mechanically efficient, coordinated and controlled performances.

To test the second hypothesis, a score of locomotion performance, ranging from -14 to +14, was calculated by using the seven items regarding walking in the gross-motor section of the EMQ: (1) *When placed into a standing position, your child will take a few (wobbly) steps while holding on to you with one hand*; (2) *When placed into a standing position, your child walk 4 or 5 steps independently with arms raised*; (3) *When moving around freely, your child will demonstrate walking on toes for a short time*; (4) *When walking down a hallway or small room, your child will walk straight for a few (4-5) steps with arms up*, (5) *walk straight without bumping into the walls using arms to balance*, (6) *walk straight with arms lowered and swinging freely*; (7) *During free play or pretend play, you notice your child can walk backwards for several (5 or more) steps.* Subsequently, we divided the sample into three groups based on the infant's locomotion performance, in line with the theoretical model presented above (Gallahue et al., 2012): (1) the first group (Low-performance group, N = 18) performed between -14 and -10 scores, which means that infants did not start walking and used crawling as the main form of locomotion; (2) the second group (Medium-performance group, N = 12) performed between -9 and + 7 scores, which means that infants were novel walkers, have just started to walk but continued to use crawling to move in space daily; (3) the third group (High-performance group, N = 20) performed between 8 and 14 scores, which means that infants had started to use walking as the main form of self-locomotion in everyday life.

Language Measures

We used three language measures: (1) communicative behaviors, (2) receptive vocabulary, and (3) productive vocabulary. All measures were derived from *The McArthur-Bates Communicative Development Inventory*

(CDI)‘Gestures and Words’ (Italian version by Caselli et al., 2015). The CDI is a parent-report questionnaire assessing language development in infants and toddlers between 8 and 36 months of age, composed of two versions: 'Gestures and Words' for 8- to 24-month-old children, and 'Words and Phrases' for 18- to 36-month-old children. Each version is available in two forms - long and brief. We used the 'Gestures and Words' short form, which includes three parts: (1) a checklist of 100 words that allows parents to mark words that their child understands (receptive vocabulary) and words that their child says (productive vocabulary); the score of both receptive and productive vocabulary was calculated by summing the words the child, respectively, understands and says; (2) a list of 18 actions and gestures that an infant between 8 and 24 months could typically perform, but we did not use in the present study; and (3) a list of 18 communicative behaviors indicative of different language abilities: attention to language and contextual/linguistic comprehension (6 items, such as ”If you name an object, the child points to or takes the named object”), phonological abilities and first linguistic production (6 items, such as ”The child uses simplified words but makes herself understood by everyone”) and gestural ability including deictic and symbolic gestures (6 items). The score was calculated by summing the communicative behaviors the child was reported to use. The sum was used as a measure of the repertoire of communicative behaviors.

Results

Descriptive and Preliminary Analyses

Descriptive statistics for all motor and language variables are presented in Table 3. The communicative behaviors score of one child at 8 months and receptive vocabulary score of another child at 12 months were missing due to incomplete questionnaires. Since missing data was less than 1% and were *Missing Completely At Random* (MCAR), we managed them by applying the pairwise deletion (Chemolli & Pasini, 2007; Heitjan & Basu, 2012). Crawling performance and locomotion performance scores from parental questionnaires were checked by the first author using available videos of daily play activities made around 8 months (86%) and 12 months (82%) during the scheduled visits or directly by parents when visits were not carried out due to the Covid-19 pandemic restrictions. In addition, all variables were checked for extreme scores to identify outliers (> 2 SD above or below the mean). The scores of four outliers (two on receptive vocabulary at 12 months and two on productive vocabulary at 16 months) were winsorized (Field, 2013) to a value of 2 SD above the mean.

Table 3

Descriptive Statistics for Motor and Language Variables

	N	*M*	*SD*	Range
Motor variables				
Crawling performance at 8 months	50	-. 24	3.85	-6-+6
Walking performance at 12 months	50	-.46	9.72	-14-+13
Language variables				
Communicative behaviors at 8 months	49	4.43	1.21	2-7
Communicative behaviors at 12 months	50	8.88	2.63	3-15.00
Receptive vocabulary at 12 months	49	32.47	19.44	4-75
Receptive vocabulary at 16 months	50	61.62	22.17	8-99
Productive vocabulary at 16 months	50	10.78	9.11	1-31

The distributions of all language (i.e., dependent) variables were tested with the Shapiro-Wilk test (Table 4). The results revealed that only the distribution of two variables –communicative behaviors at 8 months and productive vocabulary at 16 months– showed significant deviations from normality ($p < .001$). Nonparametric statistics were therefore run in analyses involving these variables.

Table 4

Checking for Normal Distribution of the Language Variables

Variables	*Shapiro-Wilk test*	
Communicative behaviors at 8 months	.901	< .001*
Communicative behaviors at 12 months	.979	.529
Receptive vocabulary at 12 months	. 956	.065
Receptive vocabulary at 16 months	.975	.377
Productive vocabulary at 16 months	.876	< .001*

* Significant deviation from a normal distribution.

As a preliminary analysis, we run a series of one-way analyses of variance (ANOVAs) and chi-squared tests to control whether the three groups of infants based on crawling performance at 8 months (to test the first hypothesis) and the three groups of infants based on locomotion performance at 12 (to test the second hypothesis) differed in characteristics (maternal education, family SES, and infant gender and birth order) that have been shown to have a role in language acquisition. No significant differences were found either among the three groups based on crawling performance at 8 months (maternal education, p = .187; family SES, p = .504; infant gender, p = .193; birth order, p = .602) or among the three groups based on locomotion performance at 12 months (maternal education, p = .325; family SES, p = .926; infant gender, p = .931; birth order, p = .373). .

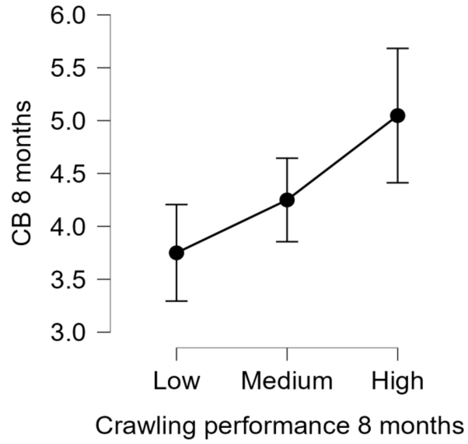
Crawling Performance at 8 Months and Concurrent and Later Language Abilities

To test whether infants with high crawling performance have better concurrent and/or later communication and language abilities than peers with lower performance, a Kruskal-Wallis test and two one-way analyses of variance (ANOVAs) were computed, respectively, on communicative behaviors at 8 months, and communicative behaviors and receptive vocabulary at 12 months, with crawling performance at 8 months at three levels (high, medium, low) as the between-subject factor. A non-parametric analysis (Kruskal-Wallis) was used on communicative behaviors at 8 months because of the non-normal distribution of these data.

The Kruskall-Wallis test showed a significant effect of crawling performance at 8 months on the repertoire of communicative behaviors at the same age, $H(2)=8.903$, p = .012 (Figure 1). In particular, a Dunn's post-hoc test revealed that infants performing higher in crawling showed a broader repertoire of communicative behaviors than infants performing lower (p = .004). No significant differences in the repertoire of communicative behaviours at 8 months were found between low- and medium performers in crawling (p = .296), and medium- and high performers (p = .256).

Figure 1

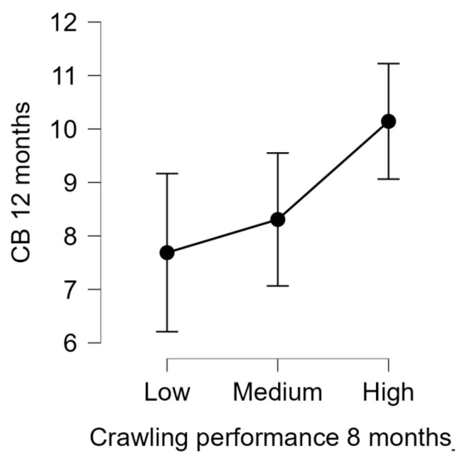
Communicative Behaviors at 8 months as a Function of Crawling Performance at the Same age. Error Bars Represent Standard Errors. CB = Communicative Behaviors



The first one-way ANOVA showed a pattern similar to the previous one, with a significant effect of crawling performance at 8 months on the repertoire of communicative behaviors at 12 months, $F(2, 47) = 9.611$, $p = .010$, $\eta_p^2 = .178$ (Figure 2). In particular, a Tukey post-hoc test revealed that infants performing higher in crawling showed a broader repertoire of communicative behaviors than infants performing lower ($p = .012$). No significant differences in the repertoire of communicative behaviours at 12 months were found between low- and medium performers in crawling ($p = 1.00$), and medium- and high performers ($p = .114$).

Figure 2

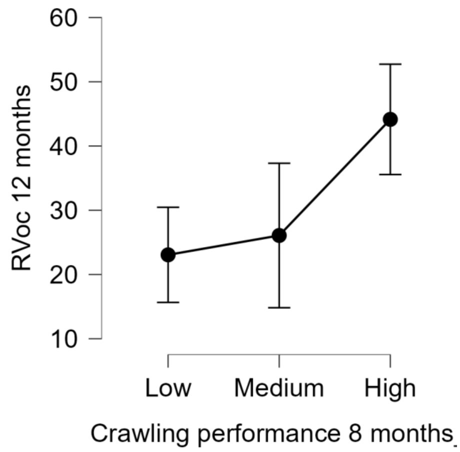
Communicative Behaviors at 12 Months as a Function of Crawling Performance at 8 months. Error Bars Represent Standard Errors. CB = Communicative Behaviors



The second one-way ANOVA showed a significant effect of crawling performance at 8 months on receptive vocabulary at 12 months, $F(2, 46) = 2337.89$, $p = .001$, $\eta_p^2 = .258$ (Figure 3). In particular, a Tukey post-hoc test revealed that infants performing higher in crawling showed a richer receptive vocabulary than both infants in the Low-performance group ($p = .002$) and infants in the Medium-performance group ($p = .014$). No significant differences in the receptive vocabulary size at 12 months were found between low- and medium performers in crawling ($p = 1.00$).

Figure 3

Receptive Vocabulary Size at 12 Months as a Function of Crawling Performance at 8 months. Error Bars Represent Standard Errors. Rvoc = Receptive Vocabulary



Locomotion Performance at 12 Months and Concurrent and Later Language Abilities

To test whether infants with high locomotion performance at 12 months have better concurrent and/or later communication and language abilities than peers with lower performance, three one-way analyses of variance (ANOVAs) and a Kruskal-Wallis test were computed, respectively, on communicative behaviors and receptive vocabulary 12 months, and receptive and productive vocabulary at 16 months, with locomotion performance at 12 months at three levels (high, medium, low) as the between-subject factor. A non-parametric analysis (Kruskal-Wallis) was used on productive vocabulary at 16 months because of the non-normal distribution of these data.

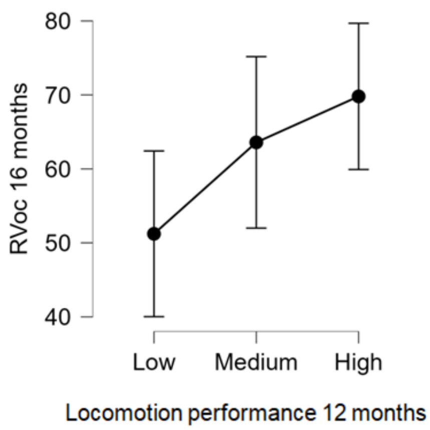
The first and the second one-way ANOVAs showed no significant effect of locomotion performance at 12 months on communicative behaviors and receptive vocabulary at the same age (p = .164 and p = .335, respectively).

The third independent one-way ANOVA showed a significant effect of locomotion performance at 12 months on the receptive vocabulary at 16 months, $F(2, 47) = 3330.55$, $p = .030$, $\eta_p^2 = .138$]. In particular, a Tukey post-hoc test revealed that infants performing higher in locomotion showed a richer receptive vocabulary than infants performing lower (p = .027). Standar errors, however, revel a high within-group variability in the receptive vocabulary size, particularly in the low-performance group. No significant differences in the receptive vocabulary size at 16 months were found between low- and medium performers (p = .364) and between medium- and high performers (p = 1).

Finally, the Kruskall-Wallis test showed no significant effect of locomotion performance at 12 months on productive vocabulary at 16 months, H(2)=4.296, p = .117.

Figure 4

Receptive Vocabulary Size at 16 months as a Function of Locomotion Performance at 12 months. Error Bars Represent Standard Errors. Rvoc = Receptive Vocabulary



Discussion

The present study aimed to investigate the potential contribution of self-locomotion to language acquisition. Our data suggest that the self-locomotion experience, especially crawling, could play a role in language development. The results that infants with a high crawling performance at 8 months have better concurrent and later communication abilities and larger receptive vocabulary at 12 months than peers with lower performance confirm our first hypothesis. The underlying idea is that the onset of self-locomotion triggers a pervasive set of changes in the child's everyday life (Campos et al., 2000), including language learning. Indeed, crawling offers infants all benefits of independent mobility: they can move through and explore the environment, control their proximity to objects and people (Campos et al. 2000; Gibson, 1988) and simultaneously move in space and direct attention to objects and people with whom their interact. This new locomotor status drastically changes infants' experience with their physical and social environment and provides them with new opportunities to practice skills that are relevant for both general communicative development and the acquisition of language.

On the contrary, our second hypothesis (on the effects of walking on communicative and language development) is only partially confirmed. With regards to communicative behaviors, our results deviate from those by Clearfield (2011), who found that, at 12 months, walkers used more communicative behaviors compared to crawlers; on the contrary, they are in line with those by Bradshaw et al. (2018), who found that walking status had little to no impact on social communication behaviors. The differences may depend on the measures used. Our measure is based on the checklist of communicative behaviors included in the CDI-“Gestures and Words”, which is a checklist including several types of gestures and communicative behaviors, whereas Clearfield (2011) coded specific gestures such as pointing to an object and waving an object specifying whether they were directed to an adult. Differently, the measure used by Bradshaw et al. (2018) is based, like ours, on a standardized assessment, the CSBS (Communication and Symbolic Behavior Scales), including a broader range of communicative behaviors. Regarding receptive and productive vocabularies, our results do not confirm those of previous studies that found that walking infants had a richer receptive and productive vocabulary compared to crawling peers (He et al., 2015; Walle & Campos, 2014; West et al., 2019). However, other studies did not find any significant difference in language abilities between walking and crawling peers (Karasik et al., 2014; Moore et al., 2019). All the cited studies, including ours, used the MacArthur-Bates-CDI to assess vocabulary size, but the walking measures and scores differed. In some studies, walking was operationalized as the infant's ability to ”take three consecutive, alternating, and independent steps with no support from furniture or caregivers” (West et al., 2019) or ”infant bipedally locomoting ten feet without falling and requiring support to walk unsupported” (Walle & Campos, 2014) and measured longitudinally in a window of a few months surrounding infants' walking onset (regardless of their chronological age). Differently, we assessed the level of walking performance ranging from low to medium to high at a fixed age, around the first birthday (see the Procedure and Measures section).

Finally, we found an effect of locomotion performance on receptive vocabulary at 16 months, with infants performing higher in locomotion at 12 months (infants who had started to use walking as the main form of locomotion) showing a richer receptive vocabulary than peers performing lower at the same age (infants who used crawling as the main form of locomotion and had not yet started walking). This finding suggests that walking may affect language acquisition in short- to medium period. This kind of effect is in line with Lüke et al. (2019) findings, which show a predictive relationship between the onset of walking and language abilities at 24 months but not later, suggesting a contribution of walk onset to an initial increase in language acquisition.

Study 2

Study 2 has two main aims. The first aim is to examine whether and how the infant’s locomotor status (crawling vs non-crawling infants at 8 months, walkers vs crawlers at 12 months, and expert walkers vs novel walkers at 16 months) may affect parents’ language directed to the infant. To this end, we explore possible differences in quantity, quality (vocabulary diversity and complexity), and communicative functions of parents' verbal input. On the basis of the literature reviewed in the Introduction, we expect that parents of crawling infants at 8 months, compared with parents of non-crawlers, use more prohibition directives to control their infant's behaviors and forbid her to do something or go somewhere. We also expect that parent's prohibition directives associated with a higher locomotor status decrease at 12 months, when all infants are locomotors, though in different ways, and disappear at 16 months, when all infants are walkers, though with different expertise. Furthermore, we expect a different trend of parents' action requests, that is, that at 8 months parents of crawlers, compared with parents of non-crawlers, do not use more action requests because their attention is on curbing the infant's motor behaviors through prohibitions, rather than urging them through specific requests for action. On the contrary, we expect that at 12 and 16 months, parents of infants with higher expertise in locomotion address more action requests to their infants than parents of age-mates with lower locomotor status. We do not have specific hypotheses on how other parents' language functions or structural characteristics might be affected by the infant's motor skills.

The second aim is to explore whether the infant's locomotor status may concur with the quantity/quality of parents' input (e.g., vocabulary diversity or language scaffolding/verbal requests aimed to promote language acquisition) in predicting infant communication and language abilities in a short-term, controlling for the infant's earlier communication skills. In the light of results from Study 1, we expect that: (a) controlling for the infant's earlier communication skills or the infant's gender when the earlier measure was non available, locomotor status at 8 months (crawlers vs non-crawlers) concurs with parents' verbal input (particularly language scaffolding or verbal requests aimed to promote language acquisition) in predicting the repertoire of communicative behaviors at 8 and 12 months, and receptive vocabulary at 12 months; (b) controlling for the infant's earlier communication skills, locomotor status at 12 months (walkers vs crawlers) concurs with parents' language scaffolding in predicting receptive vocabulary at 16 months.

Method

Participants

Participants in this study are a subset of the sample involved in Study 1, including 31 infants (45% girls, 64% firstborn) and their parents. There was no attrition. The sociodemographic characteristics of participants are reported in Table 5.

Table 5

Infants' and Parents' Characteristics

Characteristics	*M (SD)*	*Range*
Infants		
Gestational age (weeks)	39.86 (.9)	37-42
Birth weight (Kg)	3.37 (.48)	2.17-4.39
Parents		
Maternal age (years)	34.84 (3.9)	26-45
Maternal education (years)	17.19 (2.79)	13-24
Paternal age (years)	38.71 (5.5)	29-54
Paternal education (years)	14.29 (2.95)	8-18
Family		
Socioeconomic status[a]	2.73 (.63)	1.5-4

Note. [a] SES was calculated following Pierrehumbert et al., 2003.

Procedure and Measures

The procedure to collect data was the same as used in Study 1. Parents' verbal input was coded from videos made in the family's home during visits scheduled at 8, 12 and 16 months[3]. Due to the Covid-19 pandemic restrictions, both parents often stayed home during scheduled visits. Parent-infant interaction was therefore videotaped either with one parent, mostly the mother (for 24 infants at 8 months, 23 at 12 months, and 22 at 16 months), or with both parents together (for 7 infants at 8 months, 8 at 12 months, and 9 at 16 months). Parents and infants were

[3] Videos were made directly by parents when visits were not carried out due to the Covid-19 pandemic restrictions.

videotaped for approximately 10-minutes during daily play activities. Parents were asked to play with their infants as they used to. During videotaping, the researcher remained in the background and did not engage with the parent or the infant unless the parent had a question or the infant was in danger. The videos were then edited to remove interruptions (e.g., stopping for drinking, changing the nappy, or another family member entering the setting). Parents' language input was transcribed and coded during the first five minutes of uninterrupted play activities. First, parents' input was entirely transcribed using CHAT (Codes for the Human Analysis of Transcripts), which is part of the Child Language Data Exchange System (CHILDES, MacWhinney, 2000). Each line of transcription included just one utterance produced by the parent. According to Cresti and Moneglia's criterion (Cresti & Moneglia, 1997), an utterance is a production unit representing a comprehensive intent indicated by intonation and/or pause. Each parent's utterance was then coded in categories of communicative functions (see below). The structural characteristics of the parents' language input were obtained using the CLAN (Computerized Language Analysis) program included in CHILDES.

Infant's Motor Measures

As motor measures, we used the infant's locomotor status at each observation point (8, 12, and 16 months). We chose this measure because a change in locomotor status is evident and easily seen by parents; consequently, it is more likely that it could affect parents' language and behaviors. Locomotor status was defined based on the age of crawling and walking onset that parents reported in the "At which age?" section of the Baby Diary (for more details, see Study 1, Procedure and measures). We defined two different locomotor statuses for each observation point: (1) at 8 months: crawlers (N=16) *versus* non-crawlers (N = 15); (2) at 12 months: walkers (N = 15) *versus* crawlers (N = 16); (3) at 16 months: "expert" walkers (N = 16) *versus* novel walkers (N = 15) based on the length of their walking experience. Expert walkers had a walking experience of more than three months and could walk straight and rather quickly with their arms lowered; novel walkers had a walking experience of less than three months and walked for short distances with their arms up, using them to balance.

Infant's Language Measures

We used five infant's language measures derived from *The McArthur-Bates Communicative Development Inventory (CDI) 'Gestures and Words'* (Italian version by Caselli et al., 2015): repertoire of communicative behaviors at both 8 and 12 months; receptive vocabulary at both 12 and 16 months; productive vocabulary at 16 months (for more details, see Study 1, Procedure and Measures section).

Parents' Verbal Input

First, from the transcriptions, we derived five measures of the structural characteristics of parents' language: (1) number of utterances; (2) number of word tokens (the total number of words produced) as an index of quantity; (3) number of word types (number of different words) and (4) Types/Tokens Ratio (TTR) as an index of vocabulary diversity; (5) Mean Length of Utterance (MLU) as an index of complexity. Secondly, all parents' utterances were coded according to the categories of parents' communicative functions adapted from Lavelli et al. (2015) and Longobardi et al. (2015). Six mutually exclusive categories were used: (1) Directives: Any parent's utterance aimed to control the infant's behavior or prohibit doing something (e.g., "Don't go up the stairs", "Don't touch it!"; directives correspond to 'prohibitions' used by Campos et al. (1992); (2) Action requests: Any parent's utterance aimed to stimulate the infant to do something (e.g., "Bring it here", "Open the box"); action requests correspond to 'action directives' used by Adolph et al. (2014); (3) Verbal requests: Any parent's utterance aimed to elicit an adequate communicative reply from the infant, such as a pointing gesture, or to stimulate the infant to talk (e.g., "What do you want?", "Where is the cat?"). (4) Language scaffolding: Any parent's utterance aimed to support the infant's language acquisition through labeling, description of objects/actions, and correct repetition of the infant's unintelligible or incorrect word (e.g., Mother: "What are we doing?" Infant: "…"(unintelligible vocalizing) Mother: "We are building a tower!"; Mother: "Ball!" Infant: "all" Mother: "Not *all*,.. but *ball*"). (5) Positive feedback: Any parent's utterance aimed to highlight an infant's action well done and encourage her (e.g., "Very good!"). (6) Affirmation: Any interjection (e.g., "Well", "Really?") or parent's utterance which acknowledges the infant's behavior (e.g., ”Thank you”). We computed the proportion of each category of communicative function on the total number of utterances produced by parents in the coded 5-minute-videos.

Reliability

Inter-coder reliability for the transcription of videotaped sessions and the coding of parents' verbal input functions was calculated on a random sample of 15% of videos for each observation point (i.e., infant age). The reliability of transcripts was assessed as percent agreement for each structural characteristic measured: number of tokens ranged from 89% to 100%, number of types ranged from 80% to 99%, number of utterances ranged from 80% to 99%, and MLU ranged from 85% to 97%. The inter-coders reliability for communicative functions of parents' input was calculated as Cohen's kappa. The average kappa was .83 (range .77–.90).

Results

Descriptive and Preliminary Analyses

Descriptive statistics for infant's language variables and parents' verbal input are presented, respectively, in Table 6 and Table 7.

The parents' verbal input of one infant at 8 months and one infant at 16 months could not be coded for technical reasons (problems with the audio of the video). Moreover, a session of parent-infant interaction during play at 12 months was excluded because the parents videotaped it out of the family's home, in a very different context. Since missing data was less than 1% and were *Missing Completely At Random* (MCAR), we managed them as in Study 1.

Table 6

Descriptive Statistics for Infants' Language Variables

	N	*M*	*SD*	Range
Communicative behaviors at 8 months	31	4.52	1.18	3-7
Communicative behaviors at 12 months	31	8.52	2.29	4-13
Receptive vocabulary at 12 months	30	32	18.7	4-73
Receptive vocabulary at 16 months	31	62.2	19.1	23-99
Productive vocabulary at 16 months	31	10.2	9.15	1-31

Table 7

Descriptive Statistics for Structural Characteristics and Communicative Functions (percentage on total utterances) of Parents' Verbal Input During 5 min of Parent-Infant Interaction

	N	8 months		12 months		16 months	
		M (SD)	Range	*M (SD)*	Range	*M (SD)*	Range
Structural characteristics							
Number of word tokens	30	168.70 (82.61)	9-359	194.67 (81.95)	63-394	215.5 (91.21)	78-407
Number of word types	30	87.27 (36.21)	6-145	93.63 (26.65)*	55-132	105.87 (40.36)*	47-186
Tokens/Types Ratio (TTR)	30	.552 (.126)	.257-.887	.505 (.105)	.325-.753	.510 (.101)	.337-.711
Number of utterances	30	57.60 (24.38)	6-103	65.83 (22.11)	29-116	71.60 (26.62)	30-127
Mean Length of Utterance (MLU)	30	3.45 (0.32)	3.19-3.93	3.60 (0.39)	3.21-4.19	4.08 (0.48)	3.29-4.53
Communicative functions							
Directives	30	4.86 (6.37)*	0-21.58	3.56 (4.4)*	0-13.28	5.31 (4.85)*	0-17.39
Action requests	30	14.76 (9.44)*	2.99-37.01	20.51 (13.61)	0-50	16.50 (10.02)*	0-38.26
Verbal requests	30	15.89 (7.75)*	4.44-32.12	15.95 (11.22)*	0-39.53	17.89 (7.79)	4.35-37.07
Language scaffolding	30	54.39 (12.29)	25.45-78.13	50.83 (16.74)	15.30-79.69	53.51 (12.13)	28-26-70.59
Positive feedback	30	6.14 (5.66)*	0-19.44	5.69 (4.29)*	0-15.79	4.60 (4.31)*	0-13.95
Affirmations	30	3.96 (4.61)*	0-15.39	3.46 (6.02)*	0-27.59	2.19 (4.07)*	0-20.51

* Significant deviation from a normal distribution.

The distribution of all variables was tested with the Shapiro-Wilk test. The results revealed that almost half variables had a distribution that deviated from normality (see Table 7). Nonparametric statistics were, therefore, run in subsequent analyses involving those variables. Then, all row scores were z-transformed to be used in hierarchical linear regressions ran to accomplish the second aim. As in Study 1, we carried out some preliminary analyses. We first checked whether the parents' verbal input in mother(father)-infant dyads and mother-father-infant triads differed in any structural characteristics or categories of communicative functions. A series of t-tests and Mann-Whitney U tests showed no significant differences between dyads and triads either at 8 or 12, or 16 months. Subsequently, we ran a series of t-tests and Mann-Whitney U tests for continuous variables and chi-squared tests for categorical variables to control whether the two groups of infants based on their locomotor status (crawlers *versus* non-crawlers at 8 months; walkers *versus* crawlers at 12 months; and expert walkers *versus* novel walkers at 16 months) differed in factors (maternal education, family SES, and infant gender and birth order) that have been shown to have a role in language acquisition. No significant differences were found between groups either at 8 or 12, or 16 months.

Infant Locomotor Status and Structural Characteristics of Parent's Verbal Input

To test whether infants with different locomotor statuses elicit different amounts (number of tokens) or different variety (number of types, and TTR) or complexity (MLU) of verbal input from their parents at 8, 12, and 16 months, a series of independent-samples t-tests and two Mann-Whitney U tests (on not-normally distributed number of types at 12 and 16 months) were computed. No significant differences were found in any structural characteristics of parents' language addressed to infants with higher vs lower locomotor status at any age.

Infant Locomotor Status and Communicative Functions of Parents' Verbal Input

To test whether communicative functions of parents' verbal input are affected by the infant's locomotor status at 8, 12, and 16 months, a series of Mann-Whitney U tests (due to the non-normal distribution of several categories of communicative functions at all or some ages) and independent-samples t-test were computed on the categories of communicative functions used by parents during interactions with their infants at the three different ages. Descriptive statistics are displayed in Table 8.

Table 8

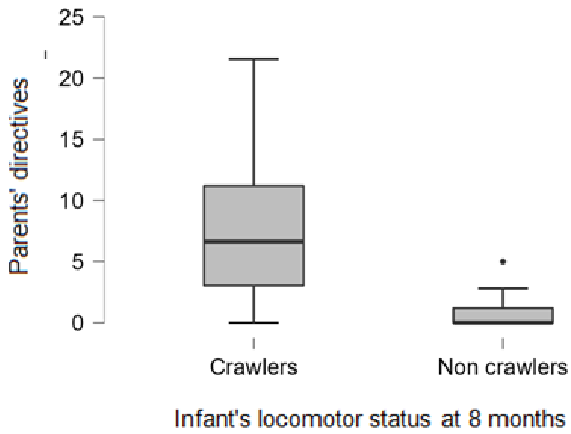
Descriptive Statistics for Parents' Communicative Functions by Infant's Locomotor Status at 8, 12, and 16 Months

	8 months		*12 months*		*16 months*	
	Crawlers	*Non-crawlers*	*Walkers*	*Crawlers*	*Expert walkers*	*Novel walkers*
Directives						
Median	6.65	0	3.15	.75	5.96	4.25
Mean	8.39	.84	4.35	2.29	6.03	5.01
Action requests						
Median	11.99	12.41	18.53	16.29	13.57	18.06
Mean	13.66	15.95	19.96	20.66	16.19	19.12
Verbal requests						
Median	14.98	15.84	11.99	12.83	14.34	17.75
Mean	15.45	16.38	14.77	17.32	16.02	16.98
Linguistic scaffolding						
Median	56.59	52.50	54.28	48.46	57.89	52.17
Mean	54.18	54.07	51.45	50.83	53.83	51.95
Positive Feedback						
Median	3.38	9.08	4.22	5.13	4.63	3.19
Mean	3.83	8.75	5.27	5.92	5.08	3.86

The results showed that, at 8 months, parents of crawling infants used significantly more directives (Mdn = 6.65) than parents of non-crawlers (Mdn = 0), U = 206.5, $p < .001$, as visualized in Figure 5. The rank-biserial correlation (r_B) (.844) indicates that this is a large effect. No significant differences were found between the amounts of parents' directives addressed to walkers vs crawlers at 12 months and expert walkers vs novel walkers at 16 months.

Figure 5

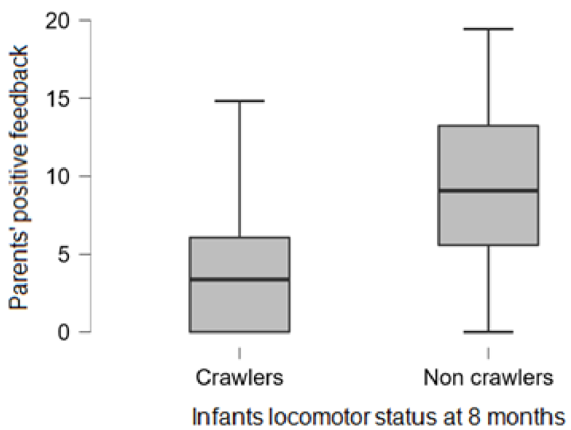
Median Values of Parents' Directives Addressed to Crawlers vs Non-crawlers at 8 months



The results also showed that at 8 months, parents of non-crawlers offered a significantly larger amount of positive feedback (Mdn = 9.08) to their infants than parents of crawlers (Mdn = 3.37), U = 59.50, p = .015, as visualized in Figure 6. The rank-biserial correlation (r_B) (.469) suggests that this is a medium effect. On the contrary, no significant differences were found between the amounts of parents' positive feedback addressed to infants with higher vs lower locomotor status at 12 and 16 months.

Figure 6.

Median Values of Parents' Positive Feedback Addressed to Crawlers vs Non-crawlers at 8 months



No significant differences were found between the amounts of parents' action requests, verbal requests, and linguistic scaffolding addressed to infants with higher vs lower locomotor status at any observed age.

Locomotor status at 8 Months and Concurrent and Later Language Abilities

First, we examined whether controlling for the infant's earlier communication skills, locomotor status at 8 months concurs with measures of parents' input in predicting communication/language abilities at the same age and four months later. To this end, we conducted a series of hierarchical multiple regressions with communicative behaviors at 8 and 12 months, and receptive vocabulary at 12 months as criterion variables, the earlier measure of infant communication skills as control, and one measure of parents' input per model[4] and locomotor status as predictors. Four measures were used for parents' verbal input: one measure of quantity (tokens) and three measures of quality (types, that is, vocabulary diversity; language scaffolding; and verbal requests encouraging the infant to reply). Because no measure of infant communication ability was collected before 8 months, when communicative behaviors at 8 months were considered as a criterion variable, the models accounted for infant gender. This variable was selected based on the literature on gender differences in early language development (see Adani & Cepanec, 2019, and Rinaldi et al., 2021, for recent reviews). Collinearity statistics, Tolerance and VIF were checked in all models: no assumptions were violated. The Q-Q plots showed that the standardized residuals fit along the diagonal for each model, suggesting that the assumptions of both normality and linearity were not violated.

In the best of the regression models, locomotor status at 8 months combines with infant gender and parents' verbal requests to explain approximately 33% of the variance in the repertoire of communicative behaviors at 8 months, as shown in Table 9. In this model, when locomotor status at 8 months was added to the other predictors, the Adjusted R^2 statistic increased by approximately 15%.

[4] We used a maximum of three predictors in each model due to the small sample size (10 data points per predictor).

Table 9

Predicting the Repertoire of Communicative Behaviors at 8 months

Model	R^2	*Adjusted* R^2	*Std. Error*	*F*	*p*	*Beta*	*p*
1[a]	.140	.109	.267	4.55	.042		
(constant)							<.001
Gender						.742	.042
2[b]	.238	.181	.477	4.21	.026		
(constant)							<.001
Gender						.737	.036
Parents' verbal requests 8m						.313	.073
3[c]	.398	.328	.444	5.72	.004		
(constant)							<.001
Gender						.522	.107
Parents' verbal requests 8m						.339	.035
Locomotor status 8m						.818	.014

[a,b,c] Dependent variable: Repertoire of communicative behaviors at 8 months.

[a] Predictors: (constant), Gender.

[b] Predictors: (constant), Gender and Parents' verbal requests at 8 months.

[c] Predictors (constant), Gender, Parents' verbal requests at 8 months and Crawling performance at 8 months.

In the other models with communicative behaviors at 8 months as a criterion variable, locomotor status at 8 months is constantly a significant predictor and explains (1) 26% of the variance in the repertoire of infant communicative behaviors when combines with parents' types and infant gender (p = .013); (2) 24% of the variance when combines with parents' tokens and infant gender (p = .018); (3) 23% of the variance when combines with parents' language scaffolding and infant gender (p = .020).

When communicative behaviors at 12 months and receptive vocabulary at 12 months were used as criterion variables in regression models, locomotor status at 8 months was no longer a significant predictor after earlier communication ability was controlled.

Locomotor Status at 12 Months and Later Receptive Vocabulary at 16 months

We examined whether controlling for the infant's earlier communication skills, locomotor status at 12 months (walkers vs crawlers) concurs with measures of parents' input in predicting language abilities at 16 months. To this end, we conducted several hierarchical multiple regressions with receptive vocabulary at 16 months as a criterion variable, the infant's communicative behaviors at 12 months as control, and one measure of parents' input per model and locomotor status at 12 months as predictors. Quantity and quality measures of parents' input were the same used in the previous analyses, but referred to parent-infant interaction at 12 months (instead of 8 months). As in previous analyses, collinearity statistics, Tolerance and VIF were checked in all models: no assumptions were violated. The Q-Q plots showed that the standardized residuals fit along the diagonal for each model, suggesting that the assumptions of both normality and linearity were not violated.

In the best of the regression models, the control factor (the earlier measure of communication skills) explains approximately 26%, that is, most of the variance explained by this model in receptive vocabulary at 16 months. When parents' language scaffolding and, in a further step, locomotor status at 12 months were added as predictors, the adjusted R^2 statistic increased by approximately 7%, although these factors were not significant predictors, as shown in Table 10.

Table 10

Predicting Receptive Vocabulary at 16 months

Model	R^2	*Adjusted* R^2	*Std. Error*	*F(d.f)*	*p*	*Beta*	*p*
1[a]	.288	.263	11.65	11.34	.002		
(constant)							.043
Comm. behaviors 12m						.573	.002
2[b]	.342	.294	1.309	7.03	.003		
(constant)							.553
Comm. Behaviors 12m						.563	.001
Parents' language scaffolding 12m						.313	.147
3[c]	.398	.328	.444	5.72	.004		
(constant)							.805
Comm. Behaviors 12						.583	<.001
Parents' language scaffolding 12m						.232	.143
Locomotor status 12m						.452	.146

[a,b,c] Dependent variable: infant's receptive vocabulary at 16 months.

[a] Predictors: (constant), infant's communicative behaviors at 12 months.

[b] Predictors: (constant), infant's communicative behaviors and parents' language scaffolding at 12 months.

[c] Predictors (constant), infant's communicative behaviors, parents' language scaffolding and locomotor status at 12 months.

Discussion

The first aim of this study was investigating whether and how infants' locomotor status at 8, 12, and 16 months may affect parents' language directed to the infant. We hypothesized that parents of crawlers at 8 months, compared to parents of non-crawlers, use more prohibition directives, but the use of directives decreases and disappears at 12 and 16 months, accordingly with the transition to a more skilled locomotor status. The results confirm both hypotheses. The results related to parent-infant interaction at 8 months are in line with previous findings by Campos et al. (1992) and Zunbahlen and Crawley (1997), highlighting that mothers of locomotor infants, compared to mothers of pre-locomotor peers, increased the number of verbal prohibitions to control their infants' behaviors after the hands-and-knees crawling onset. Indeed, when infants begin to crawl and start to explore their surroundings, they are also more likely to encounter new objects and contexts that could be dangerous to themselves. Concurrently, caregivers increase their communication to regulate their infants’ exploring, sometimes locking it to prevent infants from getting hurt. These new frames (Fogel, 1993) of parent-infant interaction provide infants with new types of social signs (verbal directives accompanied by emphasized prosody and facial/body expression) that, by emotionally engaging the infant, create new opportunities for joint attention and language acquisition. In addition, our findings suggest that the impact of crawling on parents’ verbal input is robust at early ages, when infants start independent locomotion, but decreases over time. This is understandable considering that caregivers, over time, get used to the infants’ locomotion, and the feelings of danger associated with infant exploration decrease with the increase of the infant's locomotor competence. Moreover, the parents' perception of the infant as more competent and responsible for her actions, as also reported by Campos et al. (1992), may limit their propensity to control the infant's exploration. Taken together, these findings support the idea that, when infants start self-locomotion, parents' attention is more focused on the infant's security rather than on supporting her motor performance through action requests.

Further support to our hypothesis comes from the finding confirming that at 8 months, there was no difference in parents’ action requests addressed to crawling infants and non-crawling peers. On the contrary, the findings that no differences were found between parents’ action requests addressed to crawlers vs walkers at 12 months and expert vs novel walkers at 16 months do not support our hypothesis that this type of request increases with the transition to a higher locomotor status. These findings are also inconsistent with the previous by Karasik et al. (2014), showing that mothers of walkers responded to their infants’ bids with action directives (i.e., action requests) more often than mothers of crawlers. The discrepancy may be explained considering that Karasik et al. (2014) focused on infants' social bids, that is, a specific relational situation occurring when infants share objects with their caregivers, while we considered all parents' action requests addressed to the infant during play activities. However, coming back to the discrepancy between our results and our hypothesis that advances in the infant's locomotor status could have a cascading effect on parents' amount of action requests addressed to their infant, it is possible that the parents' perception of the infant as more competent in the motor domain moves their attention from locomotor action requests to other formats of play and requests, such as those to point at a named object/person or sharing attention on new objects of interest. Finally, we found that parents of non-crawling infants at 8 months addressed more positive feedback to their infants than parents of crawlers. This result could be interpreted considering that parents' positive messages that scaffold their infant's advances in attaining new skills are likely more frequent with infants who still have to achieve a developmental milestone, such as pre-locomotor infants, than with crawlers. The latter, on the contrary, could be perceived as more skilled infants.

The second aim of the study was to explore whether the infant's locomotor status may concur with quantity/quality measures of parents' input in predicting infant communication and language abilities in the short term. Regarding the infant's locomotor status at 8 months, we found that controlling for infant gender, crawling competence concurs with a measure of parents' input (verbal requests) to explain an important portion of the variance in the repertoire of communicative behaviors at the same age. We can explain these findings considering that the onset of self-locomotion increases the opportunities for the infant to interact with different kinds of objects and situations, and these opportunities, in turn, may become new opportunities for parents to offer language input and activate communication exchanges with their infant. In addition, crawling allows the infant to move away from the caregiver, and physical distance is likely to prompt the caregiver to increase the use of language and communicative gestures to get the child's attention and prohibit/ask for action or show something interesting.

Consequently, it is more likely that crawling infants have more opportunities for communication and language learning than non-crawling infants.

Our findings confirm the hypothesis of a concurrent association between crawling skills and communication skills at around 8 months, but not the hypothesis of a predictive relationship with later communication and language abilities. On the contrary, the findings suggest that controlling for the infant's earlier communication skills, the attainment of walking at around 12 months may concur, though marginally, with other social factors such as parents' language scaffolding in promoting receptive vocabulary acquisition. Unfortunately, the small sample size limited the number of predictors we could include in the regression models. These results, however, are consistent with those found in Study 1 (infants with high performance in locomotion at 12 months had a richer receptive vocabulary at 16 months than infants with low performance) and commented above. They are also consistent with evidence from previous studies involving samples of different nationalities (Lüke et al., 2019; Walle & Campos, 2014; West et al., 2019).

General Discussion

The present study aimed to deepen the knowledge about the potential contribution of self-locomotion in language development, focusing on the crawling experience. Our findings add some evidence supporting the links between locomotion and language development in infancy and offer an original contribution suggesting links between crawling and communication and early language abilities. In the General Discussion, we deepen some of the issues introduced in the discussion of the two studies and discuss them in relation to previous works in the field.

The Contribution of Self-locomotion to Language Development: How does Time Matter?

In Chapter 1 (Systematic review, Discussion section), we highlighted that the links between motor and language development are not stable but change over time. The results of the present study suggest that the contribution of self-locomotion to language may develop through two main stages, one that follows the other amplifying its effects. In the first stage, crawling triggers the infant's first explorations of the environment with all that goes with it in terms of experiences, interactions with objects and people, and learning opportunities, including opportunities to practice skills that are relevant for both general communicative development and the acquisition of language. In the second stage, walking emphasizes previous effects of crawling, leading children to act in the environment more efficiently because hands are free to be used in communicative exchanges, and the upright position changes the point of view and increases the opportunities for interacting with objects and people. A similar trend was highlighted by Campos et al. (1997) regarding the infants' abilities of gaze-following and pointing-following during a situation of distal communicative exchanges with adults, in which the gesture was in one visual field and the gesture target in another. Both crawlers and walkers looked at the right side (i.e., at the gesture target) significantly more times than the pre-locomotor infants, although the performance of walkers was higher than that of crawlers. Different forms of self-locomotion–crawling *versus* walking–may contribute in different ways at different ages to support language development on the basis of their postural and locomotor characteristics, and the opportunities of actions that they offer.

The Contribution of Self-locomotion to Language Development: How does Space Matter?

One of the main consequences of self-locomotion onset is that it multiplies the situations in which infants get away from their parents. The infant-parent distance is a great opportunity for language learning because it requires understanding and using distal forms of communication. When infants start self-locomotion (and gets away from their parents) there is a sharp increase in the pattern of checking back and forth with the parent (Mahler, 1975), a pattern that has both a social (keeping in touch with the parent) and cognitive (jointing attention with the parent) involvement. Indeed, some studies have found positive effects of locomotion on the development of social behaviors (Clearfield, 2011), joint attention (Dillmann et al., 2019), and the understanding of intentional actions (Brandone & Eccles, 2015). Also in our observations, when a crawling infant gets away, she often points to objects near to the parent or located away from her, or draws the parent's attention using vocalizations. In other situations, parents directly activate distal communicative exchanges by asking infants to take and bring a toy located in another part of the room. This "distance condition" as a result of the onset of self-locomotion, may explain our findings on the links between locomotor status at 8 months (crawlers vs non-crawlers) and concurrent breadth of the repertoire of communicative gestures; the possibility of getting away defines opportunities to practice distal communication that, in turn, may contribute to the global language development. Moreover, our results expand the previous by Walle (2016), who found that infant initiation of joint engagement (by pointing or bringing an object to the parent) and following of the parents' joint attention cues (point following, gaze following) increased as a function of infant walking experience.

The "Participatory" Role of Self-locomotion in Language Development

Our findings support the idea that self-locomotion may participate in infant language development (Campos et al., 2000; Iverson, 2010), but the effect is not direct: parents need to play their role in reacting to the infant's self-locomotion and defining subsequent situations that are challenging for language learning. The findings highlight two different mechanisms through which self-locomotion may shape parents' behaviors to support concurrent and later infant language. The first mechanism concerns the effects of crawling onset on the use of directives. We found that infants performing higher in crawling at 8 months elicit a greater amount of directives from their parents, confirming previous results highlighted in American families (Campos et al., 1992; Zunbahlen & Crawley, 1997). Parents' directives, in turn, may activate a cascading effect on infants' language learning through a mechanism as follows. When a crawler encounters a prohibited object or enters a forbidden space, the caregiver typically responds with distal directive communication to control the infant's behaviors. Thus, the crawling infant usually responds by orienting to the caregivers, and this marks an initial phase in the development of the infant's attention to the caregiver's message. Subsequently, the crawler is motivated to discover the referent (the forbidden object or space) of the caregiver's communication. This process that may be supported by enhancing the infant's attention to distal events. As the crawler both attends to the caregiver and seeks to discover the referent of the caregiver communication, she gradually comprehends the meaning of the caregiver's head turn, gaze, pointing gestures and vocalizations; and this is a fundamental step in the gradual development of the ability to localize the target of pointing gesture smoothly and accurately (Moore, 1999). In the process described above, the onset of self-locomotion through crawling determines a substantial shift in the nature of the parents' verbal input directed toward the infants. This, in turn, triggers cascading effects on infants' basic skills that are fundamental in language acquisition, such as the ability to understand communicative input directed toward referents outside their visual field.

The second mechanism concerns the effects of both locomotor status and parents' use of strategies to scaffold the infant's language development. We found that locomotor status at 8 and 12 months concurs with measures of parents' input, such as verbal requests and language scaffolding, to explain a portion of the variance in language abilities. The onset of crawling first and walking later triggers cascading effects on infants' language learning through a mechanism as follows. When an infant starts self locomotion, she can busily act in the environment: she can move, take several objects and use them to activate social bids with her parents. In our videos, crawlers and walkers often move toward a toy, take it, and bring it to mum or dad. The parent answers with both verbal requests, "What is it?" or "What do you bring to me? This is a car!" or language scaffolding ",Thatis a very nice car!" or "The car makes brum brum". These social-communicative exchanges may facilitate matching between the word reference (directly experienced) and the word label first offered by the caregiver and then learned (understood and produced) by the child ("Car").

Limitations and Future Directions

The present study suffered from a number of limitations.

First, our sample size is relatively small, especially the Study 2 sample size. This limitation emerged particularly in analyses based on subgroup comparison and in the limited number of predictors we could include in the regression models. Thus, replication with a larger sample is needed. In addition, our sample is homogeneous: families are largely educated and have a medium SES. It is important for future research to study the potential relationships between locomotion and language abilities in more extended contexts; that is, in samples of varying demographic composition, home environments with different spatial configurations, and families with different motor and language habits.

Second, we followed the infants between 8 and 16 months longitudinally, but assessed motor and language development every four months. Although we have tracked the exact age of crawling and walking onset, we did not follow the participants with close observations, which are crucial to capture developmental change processes during transition periods (Lavelli et al., 2005/2008). Several studies have already investigated the relationship between motor and language development during the transition to walking (e.g., Walle & Campos, 2014), even considering parents' language (West & Iverson, 2021; Scheider & Iverson, 2021). However, future longitudinal studies with intensive observations of motor and communicative behaviors across and after the developmental transition from pre-locomotion to crawling are needed to deepen any cascading effect of the transition to crawling on the communication and language domain.

Third, we used parental reports to assess both motor and language development. With regards to motor development, we could control parents' assessment by analyzing videos of free-play sessions in the family home; this process made it possible to correct errors in parental reporting. We could not carry out a similar control process on language development. Although extensive validations for CDI have been reported, these measures rely on parents to accurately report their child's vocabulary. Direct testing of word comprehension and production would provide converging and more robust findings, especially during the transition to crawling, which has been little investigated until now.

Fourth, in Study 2 and 3, our observations focused on play interactions: parents were instructed to "play as you typically would". However, parents may structure play activities differently and, since we sampled only 5 minutes, we only could consider a couple of activities per session; the activities were very different from each other and, consequently, they could stimulate different verbal input from parents. For example, it is more likely that playing with a ball elicit more requests of actions in comparison with reading a book or reciting a nursery rhyme.

Future research should replicate our study with multiple observations of infants' daily routines, including different activities like meal-times or playing in the garden.

Conclusion

The onset of self-locomotion results in a global reorganization of infants daily experience and their social environment. It works as a potential fuse affecting parents' language and triggering changes in how parents communicate with their infants, which in turn may scaffold infant's language development. The infant-parent(s) dyad (or triad) works as a system: a change in one part (infant's locomotion onset) determines changes in the other parts of the system (parent's and infants' language) through processes of mutual influences.

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CAPITOLO 3

Do Motor Skills Impact on Language Development Between 18 and 30 Months of Age?[5]

[5] Il contenuto di questo capitolo è già stato pubblicato.

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Introduction

Motor development and language development have historically been considered separately and viewed as independent domains from different theoretical perspectives (e.g., Gesell & Amatruda, 1945; Lenneberg, 1967). In recent decades, however, ecological and dynamic systems approaches to development (Gibson & Pick, 2000; Thelen & Smith, 1994) and the embodied cognition approach (Clark, 1997; Varela et al., 1991) have prompted many researchers to study the co-development of motor and linguistic abilities, exploring the possibility of cross-domain interactions resulting in cascading changes throughout periods of developmental transition (Gonzalez et al., 2019). The resulting studies have highlighted both concurrent and predictive relations. Still, the findings are not consistent, probably due to the variety of assessment types used to measure motor skills and the ages at which motor and language development were assessed.

Motor Milestones Versus Global Motor Skills and Language Abilities

A group of studies have examined motor development during the first year or around the first birthday in relation to later language outcomes using the age of attainment of a motor milestone (a gross motor milestone such as sitting or walking, or fine motor milestone such as grasping) or the rate of change of that skill during a particular period. The growth of sitting skills from 3 to 5 months was found to predict receptive vocabulary at 10 months of age (Libertus & Violi, 2016) and an earlier age of independent sitting attainment was found to predict development of productive vocabulary between 16 and 28 months (Oudgenoeg-Paz et al., 2012). Most studies have focused on walking experience and compared walking and crawling infants at the same age or around the age of attainment of independent walking. Some of these studies highlighted that the walking experience significantly predicted receptive and expressive vocabularies (Walle & Campos, 2014; West et al. 2019). Some others did not find any significant difference between crawlers and walkers on their concurrent receptive and productive vocabularies (Karasik et al., 2014; Moore et al., 2019). Karasik and colleagues (2014), though, documented an interesting developmental cascade from the motor to the language domain, showing that infants' locomotor status affects the way they share objects with their mothers, which in turn elicits different verbal responses from mothers; indeed, mothers of walkers (who typically display moving bids) responded with action directives, that is, with a richer language input, more often than mothers of crawlers (who typically bid from stationary positions). In a study with a longer longitudinal design, the attainment of independent walking was found to predict development of productive vocabulary between 16 and 28 months (Oudgenoeg-Paz, 2012). However, this specific relation between gross motor milestones and later language abilities seems to become weaker or disappear at older ages (Lüke et al., 2019; Oudgenoeg-Paz et al., 2015, 2016). Finally, few studies have investigated the relationship between walking and specific linguistic categories. Within an embodied cognition approach, which views language as grounded in daily sensorimotor child-environment interactions, it was assumed that motor development can affect linguistic categories that are more related to actions, such as verbs, or more affected by motor experiences, such as spatial vocabulary (locative adverbs and prepositions, and verbs indicating movements in a direction). He and colleagues (2015) found that walking experience between 12.5 and 14.5 months of age affected more non-noun than noun vocabulary and Oudgenoeg-Paz and colleagues found that the age of independent walking predicted spatial vocabulary at 36 months (Oudgenoeg-Paz et al., 2015).

The few studies which used measures of fine motor milestones, such as the growth of grasping ability from 3 to 5 months (Libertus & Violi, 2016) and pincer grip from 8.5 to 14.5 months (Butterworth & Morissette, 1996), did not find any predictive relation with later language abilities measured between the end of the first year and the beginning of the second year.

Another group of studies investigated the relation between motor and language development using global scores of gross and/or fine motor skills. Gross motor skills refer to locomotor abilities such as walking or jumping, involving large muscle movements and coordination of arms, legs, and other large body parts; fine motor skills refer to object control skills such as grasping and object manipulation, involving small movements of wrists, hands and fingers, and eye-hand coordination. Studies which used global scores of motor skills explored both cross-sectional and longitudinal relations with language abilities at different ages.

With regard to the relation between gross motor skills and language abilities, two cross-sectional studies found significant concurrent relations at 21 months (Alcock & Krawczyk, 2010) and spanning 3 months to 3 years (Houwen et al., 2016). In both studies, however, the relations did not hold when cognitive skills and demographic variables were controlled for. Among longitudinal studies, some studies found that gross motor skills at an early time point—12 months in Longobardi et al. (2014) and 6 months in Valla et al. (2020)—predicted communicative and linguistic skills at the end of the second year, but other studies did not find any significant relationship between motor and language development (Collett et al., 2019; Leonard et al., 2015).

The findings of studies which analysed the relation between fine motor skills and language abilities in infancy and toddlerhood are also little consistent. Two studies investigated this relation concurrently (Alcock & Krawczyk, 2010; Houwen et al., 2016), but only Houwen and colleagues (2016) showed a significant positive correlation between fine motor skills and receptive and expressive language after controlling for covariates. Some longitudinal studies highlighted significant relations between a global score of fine motor skills at an early time point—12 months in Valla et al. (2020) and 18 months in Collett et al. (2019)—and later language abilities at 24 and 36 months, respectively. In contrast, Leonard et al. (2015) did not find any predictive relation between fine motor skills at 7 months and receptive and expressive language growth from 7 to 36 months. Finally, within an embodied cognition approach, Suggate and Stoeger (2014) investigated knowledge of embodied vocabulary items in preschoolers and showed that fine motor skills play a major role in the acquisition of BOI vocabulary, a selected group of items of the PPVT test (Peabody Picture Vocabulary Test) with high levels of Body-Object Interaction such as feather, shoulder and dressing (for the complete list see Suggate & Stoeger, 2014, Appendix 1). However, no studies have explored the relation between fine motor skills and specific vocabularies earlier, from the late second year across the third year.

On the whole, the findings of studies which measured motor milestones, that is specific motor skills, are more consistent than those of studies which used global scores of motor skills. Furthermore, global motor scores fail to highlight which aspect of motor skills may affects language acquisition. On the other hand, the cascading effects of specific motor milestones (measured in the first year or around the first birthday) seem to become weaker or disappear at older ages. No studies have investigated whether specific motor skills that are different from motor milestones and are measured later in the second year play a role in activating a motor-language developmental cascade.

Motor Coordination Skills and Language Abilities

When infants have achieved the main motor milestones, motor development can be observed focusing on more complex motor coordination skills. Motor coordination includes several underlying patterns of motor behavior which ensure rapid, accurate, and balanced motor response (Fernandes et al., 2016). Motor coordination can be assessed by measuring different motor behaviors at different levels of complexity (as explained in the examples below and in the Method section) and it can be divided into gross motor coordination and fine motor coordination. Gross motor coordination includes static and dynamic balance, general dynamic coordination and other specific skills. For instance, we can observe general dynamic coordination when children gain a good level of motor control in performing main daily motor behaviors, from simpler behaviors such as climbing into a low chair at around the beginning of the second year to more complex behaviors such as walking downstairs in adult manner (one foot on each step) after age 24 months (age-ranges by GMDS-R 0-2, ARICD, 1996; GMDS-ER 2-8, ARICD, 2006). A good level of motor control and balance in performing motor behaviors allows the child to move more easily and quickly in the surrounding environment, to approach a lot of new objects/events and then increase the opportunities for parents to offer a more varied linguistic input. Indeed, parents translate their children's actions and gestures referred to objects into words (Goldin-Meadow et al., 2007), but the facilitative effect of parents' responsiveness on enhancing language learning is contingent on the opportunities that children provide for parents to produce such input (Dimitrova et al., 2016).

Exner (2010) defines fine motor coordination as a group of hand skills that are needed to reach and manipulate objects. She describes different patterns of fine-motor coordination, including reaching and grasping from the first months of life, carrying and voluntarily releasing objects by the end of the first year, and more complex coordination skills which become more efficient by the end of the second year, such as object handling, manual dexterity and bimanual (or bilateral) coordination. For instance, object handling such as the use of a spoon starts at around 9 months and continues throughout infancy, becoming more and more efficient (for a detailed description see Adolph & Berger, 2015). When object handling becomes more fine and accurate, we can observe manual dexterity, and when infants and toddlers start to use both hands with a complementary differentiation of hand function (Nelson et al., 2013) we can observe bilateral coordination.

Manual dexterity, balance and coordination of arms and legs were found to be cross-sectionally associated with language abilities in preschoolers. Cheng et al. (2019) showed that manual dexterity was predictive of all language scores measured in both receptive and expressive language. Muluk et al. (2014) highlighted that the heel-to-toe walking skill at 5 years was related to the ability to define six words and count two blocks. Furthermore, Vukovic et al. (2010) found that coordination of legs, coordination of arms and imitation of complex movements were related to both comprehension and naming abilities. No studies, though, have yet explored the relation between motor coordination skills and language development during the late second and third year, considering specific linguistic categories such as noun, non-noun and spatial vocabulary.

The Present Study

Findings from previous studies have shown that the contribution of motor skills to language acquisition may depend on skill type and/or the measures used, and that the relation between motor and language development changes over time. However, several questions remain about aspects of this relation that are still unclear or little investigated: (a) Do motor skills affect language abilities also from the late second year across the third year? (b) If so, what type(s) of motor skills −global or specific (i.e., specific motor coordination skills, considering the late second year)? gross or fine? −affect language abilities? (c) Does the possible effect of motor skills on language acquisition narrow to specific language categories such as verbs and spatial vocabulary over time?

This exploratory study addresses these questions in order to enhance our understanding of the relation between motor and language development from the late second year across the third year. We examined associations between motor skills (gross and fine), assessed using both global and specific measures at 18 and 24 months, and language outcomes assessed six months later (i.e., at 24 and 30 months). In particular, we examined (a) whether gross and/or fine motor skills measured using global scores predict language outcomes in the considered age ranges; (b) whether specific gross and/or fine motor coordination skills predict language abilities in the considered age ranges; having gross-motor coordination skills such as general dynamic coordination might allow the child to use cognitive resources that were previously concentrated on performing movements to learn new concepts and words in interaction with the surrounding environment; having fine-motor coordination skills such as manual dexterity and bilateral coordination might facilitate the acquisition of vocabulary related to child-object interaction; (c) whether the possible effect of gross- and/or fine-motor coordination skills on language acquisition narrows to specific language categories that are more related to actions, such as predicates, and to motor experiences, such as spatial vocabulary, during the third year.

Method

Participants

The present study involved 36 (58% girls) Italian monolingual toddlers divided into two groups on the basis of their age: a group of 18-month-old children (N = 18) and a group of 24-month-old children (N = 18) at the time of the first assessment. All children were regularly attending nursery schools in a northeastern province of Italy. They were recruited through schools for a larger longitudinal study on children’s motor development and motor activities at school. According to their nursery teachers, none of the children had known developmental disabilities or delays, or vision or hearing problems. Children were from largely middle-class families. All parents were Italian. The demographic characteristics of the children and their parents are reported in Table 1.

Table 1

Children's and Parents' Characteristics

	18-months group (N = 18)		24-months group (N = 18)			
	n (%)	*M (SD)* Range	n (%)	*M (SD)* Range	Test between groups	*p*
Child sex (female vs male)	11 (61)		10 (56)		$\chi^2(1) = .114$	.735
Child age (months)		18.28 (1.41) 16-20		23.94 (1.77) 22-26		
Maternal age (years)		34.06 (4.34) 24-42		35.47 (4.75) 27-44	$t(34) = -.89$	.382
Paternal age (years)		38.40 (6.69) 28-53		39.41 (7.04) 30-55	$t(34) = -.42$	.681
Maternal education (years)		15.00 (2.85) 8-18		14.65 (1.90) 13-18	$t(34) = .42$	.677
Paternal education (years)		13.73 (3.63) 8-18		13.65 (2.32) 8-18	$t(34) = .08$	.936

No significant differences were found between the two groups in the children's sex and mothers' and fathers' age and education.

Parental informed consent was obtained after the study was approved (protocol n. 2015_06) by the Ethical Committee of the Department of Human Science, University of Verona.

Procedure and Measures

The study has a mixed longitudinal/cross-sectional design. Both groups of children were assessed twice, six months apart: the younger group at around 18 months (Time 1) and 24 months (Time 2); the older group at around 24 months (Time 1) and 30 months (Time 2). At Time 1, motor and language skills were measured using standardized tools administrated by a researcher in a quiet room of the nursery school, in the presence of the child's nursery teacher. The assessment was completed over three sessions lasting about 20-25 minutes, all on different days to avoid fatigue. At Time 2, only language outcomes (receptive and productive vocabulary) were assessed, using a standardized tool administered by trained nursery teachers.

Motor Measures

Motor development was assessed by using the Griffiths Mental Development Scales (GMDS) in the fall and spring of kindergarten; Scale A (Locomotor) to assess gross motor skills and Scale D (Eye and hand coordination) to assess fine motor skills. In order to address the second aim of the study, items from scales A and D were organized into four categories of gross-motor coordination skills: General dynamic coordination, Balance, Spatial organization, and Visual-motor coordination, and four categories of fine-motor coordination skills: Object handling, Manual dexterity, Bilateral coordination, and Visual-manual integration.

General dynamic coordination indicates a good level of motor control in performing main daily motor behaviors such as sitting oneself at a table at around 15-20 months or walking alone up and down stairs at around 20-24 months. Although *balance* on the legs is achieved upon acquiring walking skills at around 12-15 months, at higher coordination levels dynamic balance is shown by toddlers who walk backwards pulling a toy on string at around 16-20 months or who can rise from kneeling without using hands at around 24-28 months, and static balance is shown by toddlers who can stand on one foot for a few seconds at around the same age. *Spatial organization* is needed when children have to organize their movements in situations containing spatial hurdles such as when a toddler is trotting along a row of shrubs and needs to organize movements so as not to crash into the branches. This coordinative skill is achieved at around the end of the second year and also helps toddlers to slalom run or kangaroo jump over some blocks starting from the third year. *Visual-motor coordination* allows children to organize movements in relation to what they see while handling an object or standing close to an object of interest, for example kicking a medium-size ball at around 18-24 months and stooping to pick up a small object at around 20-24 months.

Regarding the categories of fine-motor coordination skills, *object handling* involves several motor behaviors in which children uses hands to manage objects; this skill is shown by toddlers in several daily plays such as manipulating and throwing a ball, which increases in accuracy between 13 and 22 months, or building and pushing a train with three bricks at around 24 months. *Manual dexterity* develops from fine and accurate object handling and allows toddlers, for example, to build a low tower of three or four bricks at around 15-18 months and a higher one of eight or more bricks starting from the third year. *Bilateral coordination* indicates toddlers ability to use both hands with a complementary differentiation of hand function, as when a toddler can hold a little box in one hand and put on the lid correctly using the other hand at around 15-18 months, pour liquid from one container to another at around 18-24 months, or treads beads starting from the third year. Finally, *visual-manual integration* allows children to carry out complex tasks in which several perceptual and manual motor skills need to be integrated, such as drawing perpendicular and horizontal strokes at around 20-24 months and, from around 24 months, copying figures (e.g., circle and cross) that increase in complexity across the third year. The number of items of the GMDS included for each of these categories and examples of items shown in Table 2.

Table 2

Categories of Gross and Fine motor Coordination Skills Based on Items From Griffiths Mental Development Scales

Motor skill	Description	N items	Examples of items included
Gross motor skills - Locomotor Scale			
General dynamic coordination	Child has achieved daily gross motor movements and performs them in a coordinated manner	16	A2-36 Climbs into a low chair A2-45 Can sit self at table A3-6 Walks upstairs in adult manner
Balance	Child performs both static and dynamic balance	8	A2- 42 Can walk backwards A3-2 Can stand on one foot for 3+ seconds A3-10 Can walk a chalk or painted line
Spatial organization	Child properly organizes movements in areas with spatial hurdles	4	A3-9 Jumps off two steps A3-12 Can jump over 15 cm foam hurdle A3-15 Can run fast out of door
Visual-motor coordination	Child properly organizes movements in relation to what she/he sees	6	A2-39 Stoops A2-48 Can kick a ball A3-11 Can run and kick a medium-size ball
Fine motor skills - Eye and hand coordination Scale			
Object handling	Child manipulates and properly handles objects	8	D2-38 Pulls cloths to get toy D2-41 Can throw a ball towards a person D2-48 Makes a brick or a toy "walk"
Manual dexterity	Child uses hands to perform fine and accurate movements	8	D2-42 Tower of 3 bricks D2-52 Train of 3 bricks D3-1 Builds a tower of 8+ bricks
Bilateral coordination	Child uses both hands performing different movements at the same time	5	D2-46 Can pour water from one container to another D3-3 Handle scissors: tries to cut D3-6 Folds 10.2 cm square in half
Visual-manual integration	Child properly uses a pencil to scribble and copy/draw lines and figures	13	D2-29 Can hold pencil as if to mark on paper D2-54 Horizontal stroke D3-5 Copies a circle

A second independent judge ‒an expert in motor sciences ignorant of the aims of the study ‒categorized the items on the gross and fine motor scales into the identified categories. Reliability was good for gross motor items (k = .701) and very good for fine motor items (k = .843).

Language Measures

At Time 1, language development was measured by using the *Griffiths Mental Development Scales* (GMDS-R 0-2, ARICD, 1996; GMDS-ER 2-8, ARICD, 2006), Scale C (Language and hearing), and the *McArthur-Bates Communicative Development Inventory (CDI)- Italian version-100 words* (Caselli et al., 2015), for the vocabulary checklist. At Time 2, language abilities were measured by using the *Picture Naming Game (PiNG)* (Bello et al., 2010; Bello et al., 2012). This is a standardized task which includes two subtests of lexical comprehension and production ‒the Nouns subtest (20 pictures representing objects/tools and animals) and the Predicates subtest (20 pictures representing actions, adjectives and location adverbs) ‒and allows the assessment of noun and predicate comprehension/production separately. Finally, a spatial vocabulary of 12 words in comprehension and 11 words in production was identified from the PiNG Predicate word-list, including predicates of motor actions, locative adverbs and adjectives.

Results

Descriptive statistics for gross and fine motor skills ‒both as total scores and categories of coordination motor skills‒at 18 and 24 months are reported in Table 3. Spatial organization was not included in the following analyses because more than 50% of the children did not passed any items included in this category. Object handling, was also excluded from the following analyses for the opposite reason: at 24 months all children reached the maximum score, as shown in Table 3. Descriptive statistics for language abilities as total score and vocabulary size at 18 and 24 months, and vocabulary (nouns, predicates, and spatial vocabulary) in comprehension and production at 24 and 30 months are reported in Table 4.

Table 3

Descriptive Statistics for Gross and Fine Motor Skills

		18 months		24 months	
	Score range	Observed range	M (SD)	Observed range	M (SD)
Gross motor skills total score (GMDS-Scale A) [a]		-1.19-2.04	-0.01 (1.12)	-1.32-2.66	1.12 (1.05)
General dynamic coordination	0-16	2-16	11.00 (3.41)	11-16	14.44 (1.62)
Spatial organization	0-4	0-4	0.67 (1.08)	0-3	1.22 (1.06)
Balance	0-8	0-7	2.28 (2.82)	0-8	5.17 (2.55)
Eye-motor coordination	0-6	1-6	3.83 (1.89)	3-6	5.39 (0.85
Fine motor skills total score (GMDS-Scale D) [a]		-1.03-2.25	-0.11 (1.03)	-1.21-2.66	0.91 (0.94)
Object handling	0-8	2-8	7.33 (1.50)	8-8	8 (0)
Manual dexterity	0-8	1-8	5.17 (2.20)	4-8	6.50 (1.25)
Bilateral coordination	0-5	0-4	1.33 (1.03)	0-5	1.67 (1.33)
Visuo-motor integration	0-13	3-10	7.06 (1.63)	7-13	8.78 (1.35)

[a] Z points

Table 4

Descriptive Statistics for Language Skills

		18 months		24 months		30 months	
	Score range	Observed range	M (SD)	Observed range	M (SD)	Observed range	M (SD)
Language total score (GMDS-Scale C) [a]		-1.64-2.04	-.011 (1.03)	-1.08-1.74	1.03 (0.76)	-	-
CDI Italian vers.-100 words	0-100	1-54	24.39 (22.09)	1-97	59.30 (26.46	-	-
Nouns Comprehension (PiNG)	0-20	-	-	11-20	17.44 (2.62)	16-20	18.56 (1.42)
Predicates Comprehension (PiNG)	0-20	-	-	9-20	15.50 (2.71)	11-20	17.06 (2.60)
Spatial Vocabulary Compr.(PiNG)	0-12	-	-	2-12	8.27 (1.93)	4-12	7.94 (1.55)
Nouns Production (PiNG)	0-20	-	-	0-14	10.11 (3.97)	2-18	11.56 (4.42)
Predicates Production (PiNG)	0-20	-	-	1-14	8.72 (4.36)	3-15	9.22 (3.89)
Spatial Vocabulary Prod. (PiNG)	0-11	-	-	0-10	3.76 (2.83)	0-8	3.22 (2.39)

[a] Z points

In order to assess whether gross and/or fine motor abilities predict receptive and/or productive vocabulary six months later ‒that is, at 24 months for the younger group, and at 30 months for the older group ‒we ran hierarchical linear regressions using criterion variables and predictors, based on our aims and hypotheses, separately for the two groups. The effect of linguistic abilities at Time 1 was controlled in all regression analyses. Given the small size of the two samples, we used robust statistical techniques (Maechler et al., 2018) that take into account both the violations of the main assumptions required by parametric statistical analyses and the small sample size. In addition, for regression models with more than two predictors, we carried out a retrospective power analysis using G*Power 3 (Faul et al., 2007) ‒assuming the effect size (f^2) of each model‒in order to assess that beta error was < 5% (and then the power was > 95%).

In order to examine whether gross and/or fine motor abilities measured using global scores at 18 and 24 months predict language outcomes six months later (first aim), we conducted robust regressions with noun/predicate comprehension/production as criterion variable and linguistic abilities (GMDS-Scale C) at Time 1 and global scores of gross motor skills (GMDS-Scale A) and/or fine motor skills (GMDS-Scale D) as predictors. Only the global score of gross motor skills at 18 months predicted 37% of the variance in predicate production at 24 months when linguistic abilities at 18 months were taken into account, as shown in Table 5. Fine motor skills (global score) at the same age did not predict any later language outcomes (e.g., the "best" model with noun/predicate comprehension/production at 24 months as criterion variables was: scales C, D 18m → predicate prod.24m R^2 = .129, AdjR^2 = .013). Furthermore, neither gross nor fine motor skills measured using global scores at 24 months, controlling for linguistic abilities at the same age, predicted any later language outcomes (e.g., the "best" models with noun/predicate comprehension/production at 30 months as criterion variables were: scales C, A, D 24m → noun prod.30m R^2 = .109, AdjR^2 = .084; scales C, A 24m → predicate prod.30m R^2 = .118, AdjR^2 = .000).

In order to assess whether specific categories of motor coordination skills (both gross and fine) at 18 and 24 months predict language outcomes six months later (second aim), we carried out a series of robust regressions with noun/predicate comprehension/production as criterion variable and, as predictors, linguistic abilities at Time 1 and categories of gross-motor coordination skills: general dynamic coordination and/or balance and/or visual-motor coordination, and fine-motor coordination skills: manual dexterity and/or bilateral coordination and/or visual-manual integration. Among categories of gross-motor coordination skills, general dynamic coordination at 18 months uniquely accounted for noun (but not for predicate) production at 24 months when linguistic abilities at 18 months were taken into account; the proportion of variance explained by this model was 55%, as shown in Table 6. The same skill (general dynamic coordination) at 24 months alone (i.e., without other predictors) also explained 26% of the variance in predicate production at 30 months, as shown in Table 7. No associations were found between balance or visual-motor coordination and any later language outcomes (e.g., the “best” models with noun/predicate comprehension/production at 24 and 30 months as criterion variables were: scale C, balance 24m → predicate prod.30m R^2 = .182, AdjR^2 =.073; scale C, visual-motor coordination 24m → predicate prod.30m R^2 = .159, AdjR^2 =.047). No categories of fine-motor coordination skills were found to predict noun or predicate comprehension or production at either 24 or 30 months (e.g., the “best” models with noun/predicate comprehension/production at 24 and 30 months as criterion variables were: scale C, manual dexterity 18m → noun prod.24m R^2 = .194, AdjR^2 =.087; scale C, bilateral coordination 24m → predicate compr.30m R^2 = .229 AdjR^2 =.096; scale C, bilateral coordination 24m → noun prod.30m R^2 = .162, AdjR^2 =.050).

Finally, in order to assess the hypothesis that possible effects of gross and fine motor coordination skills on language acquisition narrow to specific language categories, such as spatial vocabulary, during the third year (third aim), we carried out robust regressions with spatial vocabulary comprehension/production at 30 months as criterion variable and, as predictors, linguistic abilities at Time 1 and categories of gross-motor coordination skills: general dynamic coordination and/or balance and/or visual-motor coordination, and fine-motor coordination skills: manual dexterity and/or bilateral coordination and/or visual-manual integration. A combination of fine- and gross-motor coordination skills ─bilateral coordination and general dynamic coordination─at 24 months uniquely accounted for spatial vocabulary comprehension at 30 months when linguistic abilities at 24 months were taken into account; the proportion of variance explained by this model was 72%, as shown in Table 8. No associations were found between the other categories of gross- and fine-motor coordination skills and later spatial vocabulary comprehension or production (e.g., the "best" models with spatial vocabulary comprehension/production at 30 months as criterion variables were: scale C, balance 24m → spatial vocabulary compr.30m R^2 = .144, AdjR^2 = .057; scale C, manual dexterity 24m → spatial vocabulary compr.30m R^2 = .113, AdjR^2 = .022; scale C, visual-manual integration 24m → spatial vocabulary compr.30m R^2 = .149 AdjR^2 =.055).

Table 5

Predicting Predicate Production at 24 months

Model	R^2	*Adjusted* R^2	*Robust residual Std. Error*	*Parameter estimate*	*p*
1[a]	0.112	0.057	5.15		
(constant)				8.933	< .001
GMDScale-C 18m				1.511	.117
2[b]	0.444	0.370	3.95		
(constant)				9.331	< .001
GMDScale-C 18m				6.112	< .001
GMDScale-A 18m				- 4.847[c]	< .001

[a,b] Dependent variable: Predicate production at 24 months.

[a] Predictors: (constant), Language abilities (GMDS-Scale C) at 18 months.

[b] Predictors: (constant), Language abilities (GMDS-Scale C) and Locomotor skills (GMDS-Scale A) at 18 months.

[c] The negative sign does not indicates an inverse relation, but only that in order to

approach the points of an hypothetical straight line, the parameter estimate must be decreased.

Table 6

Predicting Noun Production at 24 months

Model	R^2	*Adjusted R^2*	*Robust residual Std. Error*	*Parameter estimate*	*p*
1[a]	0.004	-0.059[c]	1.73		
(constant)				11.832	< .001
GMDScale-C 18m				0.103	.874
2[b]	0.604	0.551	1.71		
(constant)				7.096	< .001
GMDScale-C 18m				-0.739[d]	.088
General Dynamic Coord. 18m				0.622	< .001

[a, b] Dependent variable: Noun production at 24 months.

[a] Predictors: (constant), Language abilities (GMDScale-C) at 18 months.

[b] Predictors: (constant), Language abilities (GMDScale-C) and General Dynamic Coordination (GDC) at 18 months.

[c] For the *Adjusted R^2* the negative sign indicates that the estimate of the percentage of variance explained in the population is not reliable.

[d] The negative sign does not indicates an inverse relation, but that in order to approach the points of an hypothetical straight line, the parameter estimate must be decreased.

Table 7

Predicting Predicate Production at 30 months

Model	R^2	*Adjusted* R^2	*Robust residual Std. Error*	*Parameter estimate*	*p*
1[a]	0.017	-0.045	4.765		
(constant)				4.759	.485
GMDScale-C 24m				0.082	.532
2[b]	0.301	0.208	3.550		
(constant)				-1.330	.788
GMDScale-C 24m				0.078	.474
General Dynamic Coord. 24m				0.774	.010
3[c]	0.305	0.261	3.321		
(constant)				2.656	.341
General Dynamic Coord. 24m				0.079	.008

[a, b, c] Dependent variable: Predicate production at 30 months.

[a] Predictors: (constant), Language abilities (GMDScale-C) at 24 months.

[b] Predictors: (constant), Language abilities (GMDScale-C) and General Dynamic Coordination (GDC) at 24 months.

[c] Predictors: (constant), General Dynamic Coordination (GDC) at 24 months.

Table 8

Predicting Spatial Vocabulary Comprehension at 30 months

Model	R^2	*Adjusted* R^2	*Robust residual Std. Error*	*Parameter estimate*	*p*	*Power (1-β)*
1[a]	0.282	0.237	1.06			
(constant)				7.310	<.001	
GMDScale-C 24m				1.079	.158	
2[b]	0.347	0.260	1.20			
(constant)				7.697	<.001	
GMDScale-C 24m				0.900	.122	
Bilateral Coordination 24m				-0.728	.388	
3[c]	0.765	0.715	0.79			.97
(constant)				5.608	<.001	
GMDScale-C 24m				0.995	.001	
Bilateral Coordination 24m				-2.130	<.001	
General Dynamic Coord. 24m				0.288	.007	

[a, b, c] Dependent variable: Spatial Vocabulary comprehension at 30 months.

[a] Predictors: (constant), Language abilities (GMDScale-C) at 24 months.

[b] Predictors: (constant), Language abilities (GMDScale-C) and Bilateral Coordination (BC) at 24 months.

[c] Predictors: (constant), Language abilities (GMDScale-C), Bilateral Coordination (BC) and General Dynamic Coordination (GDC) at 24 months.

Discussion

The current study increases our understanding of the longitudinal relation between motor and language development from the late second year across the third year, an age range during which this relation has been little explored. We were especially interested in investigating whether gross and/or fine motor skills measured using both global and specific scores (we used motor coordination skills as specific measures) affect language outcomes in the considered age ranges and whether the possible effect of gross and/or fine motor skills on language acquisition narrows to specific language categories: nouns, predicates and spatial vocabulary, during the third year.

In summary, our results show that motor skills affect language abilities also from the late second year and across the third year, but the impact is different according to the type of motor skills (gross vs. fine) and language abilities (type of vocabulary: nouns, predicates, and spatial terms), and children's age. Gross motor skills were significantly associated with later language outcomes over the whole age-range investigated. However, the relation changed as the children's age rose. A global score of gross motor skills at 18 months predicted vocabulary production (predicates specifically) within the end of the second year, but not later. From the late second year a gross-motor coordination skill –general dynamic coordination –was found to be associated with later language outcomes, in particular with noun production at 24 months, with predicate production at 30 months, and continuing across the third year, with spatial vocabulary comprehension (in the latter case added as predictor to bilateral coordination). Fine motor skills were not associated with any language outcomes until the third year, when a fine-motor coordination skill –bilateral coordination – combined with general dynamic coordination was found to predict spatial vocabulary comprehension.

We discuss first the impact of gross motor skills, particularly general dynamic coordination, on noun and predicate vocabularies, then briefly the results on fine motor skills and the hypothesis of a later impact of these skills on language development, and finally the impact of specific fine- and gross-motor coordination skills on spatial vocabulary.

Impact of Gross Motor Skills on Noun and Predicate Vocabularies

The result that a global score of gross motor skills at 18 months predicted predicate production at 24 months partially confirms previous studies (Lyytinen et al., 2001; Valla et al. 2020). Taking a dynamic systems perspective, better locomotor skills provide children with more extensive and varied ways to move and interact with their surrounding environment, which in turn offer them new learning opportunities, and offer their caregivers new opportunities to translate their actions into words, introducing new predicates in language input. Considering that ‘parallel talk’ (i.e., commenting on child’s actions) is an evidence-based language facilitation strategy (Donegan-Ritter & Van Meeteren, 2018; Girolametto & Weizman, 2006), we conjecture that this could play a role in the association of gross-motor skills with the development of predicate vocabulary. In addition, predicates are included in action directives, which are likely to increase in parents’ talk when children move more easily in their environment, as Karasik and colleagues (2014) have shown.

Interestingly, a specific gross motor coordination skill ‒general dynamic coordination ‒was related to noun and predicate production at different ages. High scores on general dynamic coordination show that children have consolidated the main daily gross movements such as walking or going up and down the stairs. These children don't need to "think to walk" anymore, but can simultaneously walk and direct attention to objects and people they interact with. In other words, general dynamic coordination allow children to shift their attention away from performing movement to learning new concepts and words related to new objects of interest shared with caregiver. This is in line with the idea of "internal socio-cognitive resources reallocation" involving the motor and language domains, highlighted by Geva & Orr (2016). This study showed that socio-cognitive resources are reallocated from the socio-language domain to the motor domain during the onset of walking. The authors assumed that this relation is bi-directional, so we can suppose that in the age range considered ‒in which general dynamic coordination starts supporting the efficient working of daily movements ‒ resources are reallocated in a reversed order and shift from motor to language domain. However, general dynamic coordination was found to be associated with noun production at 24 months and predicate production at 30 months. We suppose that the association between general dynamic coordination at 18 months and noun production at 24 months could be explained by a developmental cascade from the motor to the language domain that unfolds in the crucial period of the word-spurt phenomenon, and partially contributes to this. Around 18-20 months, all typically developing children have achieved a good level of independent locomotion which allow them to move more easily in the environment, to reach many objects and point to them to share attention and interest with their caregivers; the latter, in turn, offer children linguistic input, primarily labelling the object-focus of attention, which is a widely recognized strategy for language acquisition (e.g., Olson & Masur, 2015; Poulin-Dubois et al., 1995). In this perspective, children are therefore likely to receive diversified verbal input supporting their vocabulary acquisition according to not only their caregivers' responsiveness, but also the variety of objects they can approach and interact with. On the association between general dynamic coordination and predicate production, according to an embodied cognition approach, motor experience could facilitate the association between verbal labels indicating actions (e.g., "Pull!" while the child is trying to pull a small trolley) and their referents (e.g., the action of pulling).

Fine Motor Skills and Noun and Predicate Vocabularies: A Later Impact?

No global or specific scores of fine motor skills predicted noun or predicate vocabulary measured using the PiNG task at 24 and 30 months, although an association was found between bilateral coordination and spatial vocabulary in the third year (see below). These negative results are in contrast with those of two studies that found a significant relation between global scores of fine motor skills during the second year and language outcomes at 24 and 36 months, respectively (Collett et al., 2019; Valla et al., 2020). The studies are not properly comparable, however, because of the differences in the type of assessment used to measure motor and language abilities and in the ages in which motor and language development were assessed. Our results, particularly the association found between fine-motor coordination skills and vocabulary related to motor experience in the third year, suggest that fine motor skills are likely to have a later impact on language development. Indeed, both global fine motor scores and specific fine motor skills were found to be associated with language outcomes in preschoolers (Cheng et al., 2009; Suggate & Stoeger, 2014).

Impact of Fine and Gross Motor Coordination Skills on Spatial Vocabulary

A combination of specific fine and gross motor coordination skills: bilateral coordination and general dynamic coordination at 24 months predicted spatial vocabulary across the third year. This result confirms our hypothesis that possible effects of motor skills on language acquisition are likely to narrow to specific language categories related to motor experience. It is also in line with results from Oudgenoeg-Paz et al. (2015), who found that the attainment of walking is related to spatial vocabulary at 36 months. Within the framework of an embodied cognition perspective, while using motor skills to explore their environment children receive and generate sensory information, which sets the stage for language acquisition (Gogate & Hollich, 2010; Oudgenoeg-Paz et al., 2015). Bilateral coordination (the ability to use both hands with a complementary differentiation of hand function) allows children to explore the spatial properties of objects, then perceiving and acting upon properties that enable spatial relations between objects, such as the possibility of containing. For instance, while exploring the object property of containing, children experience spatial concepts such as “inside”, “outside”, “full”, “empty”, “take out”, “put in”. Often in real-time, or in a differed time, they can hear the corresponding verbal labels offered by their caregiver, then associate experience and words, and learn new words that enlarge their spatial vocabulary.

With regard to the contribution of gross-motor coordination skills, when children move themselves in the environment they gather information about space and its features. In particular, when they have a high level of general dynamic coordination and can move easily in their environment, they have continuous perception-action experiences of spatial concepts such as "height" if they climb stairs, "under" if they hide under a table, or "far" if they are asked to take an object to the other side of the room. As the object-exploration experiences, these locomotor experiences work as a scaffold that facilitates simultaneous or later coupling between concepts experienced and corresponding verbal labels and, subsequently, the acquisition of locative adverbs and prepositions and new verbs related to spatial relations.

Conclusion

Although this study is exploratory, it makes an original contribution to the literature on the relations between motor and language development. It extends previous research in two ways. First, it is the first study that uses specific measures of motor skills, other than global measures, in the little-explored period from late in the second year across the third year, by assessing motor coordination skills that are specific to that age range. Second, it adds to the literature by suggesting that motor coordination skills play a role in language acquisition between the second and third years.

The small sample size must be regarded as a significant limitation of this study when interpreting the results. Because of the small sample size, we used robust statistical analyses that avoid the production of false positives and reduce the probability of producing false negatives. However, the sample size in future studies needs to be larger and more varied (including, for example, children living in different regions and not attending nursery school) in order to assess the consistency of our findings. A large sample size will allow the use of more complex models in data analysis, controlling for factors such as maternal education or family SES. These are known to affect the home language environment, particularly the language input addressed to the child, that plays a main role in language acquisition. Another major limitation of this exploratory study is, indeed, the simplicity of the models used to assess the relation between motor skills and language outcomes. Future research should then explore more complex models, including factors that might mediate the relation between motor and language development, and controlling for more individual and contextual factors that are known to interact in affecting both motor and language development. In addition, future research should address other potential methodological weaknesses: one single large group of children should be observed longitudinally across the considered age range in order to confirm that the relation between motor and language abilities changes according to the child's age; more robust procedures should be used to identify and measure categories of motor coordination skills and explore their relations with language outcomes.

Overall, the present study deepens our understanding of the longitudinal relation between motor and language development, focusing on the late second and third years. Our findings show that in this age range it is essential to consider both gross and fine motor skills and to shift the attention from global motor scores to specific motor skills such as motor coordination skills, and from global language to specific language categories. They support, therefore, the idea that the relation between motor and language development is neither simple nor stable over time, but rather dynamic.

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CONCLUSIONI

Questa tesi amplia l'attuale conoscenza sulle relazioni tra sviluppo motorio e sviluppo linguistico nei primi anni di vita, offrendo alcuni apporti originali che ineriscono soprattutto la specificità di tali relazioni. La prospettiva di partenza assunta è che l'acquisizione e il progressivo affinamento di specifiche abilità motorie cambino il modo in cui i bambini agiscono nella loro quotidianità e il modo in cui le persone interagiscono con loro; questi cambiamenti diventano opportunità di apprendimento in grado di sostenere, attraverso meccanismi a cascata, altri apprendimenti, tra cui quello linguistico (Adolph & Hoch, 2019; Iverson, 2021; Oakes & Rakison, 2019).

Cosa è emerso dall'analisi sistematica della letteratura

L'analisi sistematica della letteratura ha suggerito la presenza di tre possibili percorsi di sviluppo che prendono avvio da alcune competenze motorie e possono sostenere lo sviluppo di abilità linguistiche: il controllo posturale, la locomozione autonoma e la manipolazione fine degli oggetti.

Lo sviluppo posturale inizia con il controllo della testa, prosegue con il raggiungimento della posizione seduta e termina con la conquista della posizione eretta. Il controllo della testa e del busto modifica il punto di vista del bambino, offrendo nuove esperienze percettive e, di conseguenza, diverse informazioni relative all'ambiente circostante. Inoltre, gli consente di girare intenzionalmente lo sguardo nella direzione desiderata, supportando le interazioni faccia-a-faccia con i caregiver e definendo contesti di attenzione condivisa, che a loro volta possono sostenere scambi comunicativi tra bambino e adulto. Il controllo della testa misurato a 6 mesi è risultato associato alla capacità del bambino di girarsi in risposta ad un suono o ad una voce alla stessa età (Muluk et al., 2016); misurato a 7 mesi, è risultato longitudinalmente associato alle abilità linguistiche sia in recezione che in produzione a 36 mesi (Collett et al., 2018). Le evidenze più consistenti riguardano la posizione seduta. Una maggiore durata nel mantenimento della posizione seduta misurata tra i 3 ei 5 mesi di età predice l'ampiezza del vocabolario ricettivo a 10 mesi (Libertus & Violi, 2016). Inoltre, i bambini che iniziano prima a stare seduti mostrano un più ampio vocabolario produttivo globale misurato tra 16 e 28 mesi (Oudgenoeg et al., 2012) e, seppur marginalmente, un più ampio vocabolario produttivo spaziale misurato a 36 mesi (Oudgenoeg et al., 2015). Rispetto al potenziale contributo della posizione eretta sullo sviluppo linguistico, Muluk et al. (2016) hanno evidenziato relazioni significative tra la capacità di stare in piedi, prima con un supporto e poi autonomamente, e il linguaggio produttivo a 12 mesi. Al contrario, Bradshow et al. (2018) non hanno rilevato differenze significative nelle abilità linguistiche tra i bambini che a 12 mesi non stavano ancora in piedi, avevano iniziato a stare in piedi e avevano già iniziato a camminare.

Il secondo, e più studiato, effetto a cascata inerisce il cammino. La maggior parte degli studi ha trovato evidenze empiriche, sia traversali che longitudinali, a supporto di un potenziale contributo del cammino alle abilità linguistiche (ad es., He et al., 2015; Walle, 2016; Walle & Campos, 2014; West et al., 2019), seppure lo stesso appaia più forte all'inizio della deambulazione e si indebolisca fino a scomparire in età avanzata (Lüke et al., 2019; Oudgenoeg-Paz et al., 2012, 2015). Gli autori avanzano diverse ipotesi in merito ai meccanismi che sottendono l'effetto del cammino sullo sviluppo linguistico: (1) movimenti più coordinati ed efficienti possono comportare una maggiore esplorazione dell'ambiente; (2) la posizione eretta facilita la respirazione favorendo il funzionamento del diaframma, e di conseguenza l'utilizzo della voce, e crea le condizioni perché gli input dei genitori siano più facilmente percepibili; (3) le mani libere possono essere maggiormente coinvolte negli scambi comunicativi, ad esempio attraverso le offerte di oggetti ad un adulto; (4) il fatto che il bambino sia in grado di spostarsi da solo può alterare la comunicazione dei genitori in linea con il fatto che il bambino venga percepito come un partner più competente. Ma è importante evidenziare che la deambulazione non inizia con il cammino, ma con il gattonamento. Eppure, questa prima forma di locomozione è stata considerata solo in alcuni studi e principalmente come stadio di sviluppo antecedente il cammino e pertanto di livello inferiore in termini di competenza; ne emerge che i bambini che camminano rispetto ai bambini di pari età che gattonano hanno abilità linguistiche più avanzate (He et al., 2015; Walle & Campos). L'unico studio che si è focalizzato sul gattonamento, lo ha indagato parallelamente alla produzione di vocalizzi da parte del bambino; il focus non era però sul possibile effetto del gattonamento sullo sviluppo linguistico, ma sull'allocazione delle risorse tra dominio motorio e linguistico durante la transizione alla locomozione autonoma. Questo dato emerso dalla letteratura ha orientato la scelta di focalizzare il nostro primo studio sul gattonamento, affiancando un approfondimento sul cammino per verificare se alcune delle relazioni emerse tra avvio del cammino e concorrenti/successive abilità linguistiche in bambini di altre nazionalità possano essere evidenziate anche in bambini di nazionalità italiana.

Il terzo potenziale effetto a cascata potrebbe essere innescato dalla manipolazione fine e da alcune capacità coordinative ad essa connesse, ma le evidenze in merito sono relativamente deboli. Le abilità fino-motorie consentono ai bambini di esplorare gli oggetti e di acquisirne una conoscenza più approfondita in termini di caratteristiche e funzioni specifiche (Lederman & Klatzy, 2009). Le esperienze senso-motorie connesse a queste dinamiche manipolativo-esplorative possono pertanto facilitare l'attribuzione di significati specifici alle caratteristiche e alle funzionalità degli oggetti, un processo che secondo Iverson (2010) può sostenere il successivo apprendimento delle parole connesse a questi significati. Sebbene la manipolazione si manifesti già nei primi mesi di vita del bambino, gli studi che l'hanno indagata nelle sue prime manifestazioni non hanno rilevato alcuna relazione significativa con le abilità linguistiche misurate successivamente (Libertus & Violi, 2016). Al contrario, alcune evidenze sono state trovate nel momento in cui le abilità fino-motorie sono state indagate in età più avanzata (Muluk et al., 2014). Nel loro insieme, i risultati suggeriscono che è probabile che le abilità motorie fini abbiano un impatto più tardivo sullo sviluppo del linguaggio e che questo impatto si restringa a specifiche abilità linguistiche come il vocabolario spaziale e altri vocabolari che potremmo definire *embodied* (parole con alti livelli di interazione corpo-oggetto; Suggate & Stoeger, 2014). Questo dato emerso dalla letteratura ha orientato alcune domande di ricerca del secondo studio empirico, volte ad indagare il potenziale contributo di alcune capacità coordinative (sia grosso- che fino-motorie) allo sviluppo di specifiche abilità linguistiche in bambini più grandi, a cavallo tra il secondo e il terzo anno di vita.

Le relazioni tra sviluppo motorio e sviluppo linguistico a cavallo tra il primo e il secondo anno d'età: il potenziale contributo del gattonamento

I risultati del nostro primo studio empirico ci hanno consentito *in primis* di evidenziare che ad 8 mesi i bambini con prestazioni più elevate nel gattonamento hanno anche abilità linguistiche migliori. Questi risultati confermano l'idea che l'avvio della locomozione autonoma innesca una serie pervasiva di cambiamenti nella quotidianità del bambino (Campos et al., 2000) e che tali cambiamenti possono influenzare anche lo sviluppo del linguaggio. I nostri risultati ampliano i precedenti che hanno considerato la locomozione autonoma, ma si sono concentrati sul cammino. Era emerso che a 12 mesi i bambini che camminano usano una maggior quantità di gesti comunicativi rispetto a quelli che gattonano (Clearfield, 2011) e hanno un vocabolario ricettivo e produttivo più ricco (He et al., 2015; Walle & Campos, 2014). Sebbene i nostri risultati confermino solo in parte quelli dei precedenti studi inerenti il cammino, nell'insieme suggeriscono che il contributo della locomozione autonoma allo sviluppo linguistico potrebbe avvenire in due fasi successive. Nella prima, il gattonamento consente al bambino le prime esplorazioni dell'ambiente con tutto ciò che ne consegue in termini di esperienze, interazioni con oggetti e persone, e opportunità di apprendimento. Nella seconda fase, il cammino enfatizza gli effetti del gattonamento, portando i bambini ad agire nell'ambiente in modo più efficiente perché le mani sono libere per essere utilizzate negli scambi comunicativi e la posizione eretta cambia il punto di vista e aumenta le opportunità di interazione con oggetti e le persone. Un *trend* di sviluppo con queste caratteristiche era stato evidenziato da Campos et al. (1997) in riferimento alla capacità del bambino di seguire lo sguardo e di indicare durante scambi comunicativi distali con gli adulti, in cui referente e target del messaggio erano in campi visivi diversi. Sia i bambini che gattonavano che quelli che camminavano rivolgevano correttamente lo sguardo per un numero maggiore di volte rispetto ai bambini che ancora non avevano avviato la locomozione autonoma, ma le prestazioni dei bambini che camminavano erano migliori di quelle dei bambini che gattonavano. Pare che diverse forme di locomozione autonoma ─gattonamento *versus* cammino─ contribuiscano in modi diversi, a diverse età, nel supportare lo sviluppo della comunicazione e del linguaggio.

Questo primo studio ha inoltre indagato se, e come, la locomozione autonoma (il gattonamento a 8 mesi e il cammino a 12 e 16 mesi) influenza e modella gli input verbali che i genitori rivolgono ai loro bambini. I risultati più significativi riguardano gli 8 mesi, in cui l'avvio o meno del gattonamento sembra condizionare sia le direttive, ovvero quelle espressioni finalizzate a controllare e contenere il movimento del bambino, sia i feedback positivi, ovvero quelle espressioni finalizzate a sostenere e rinforzare il bambino, anche se con direzionalità opposte. A 8 mesi i bambini che gattonano ricevono un numero di direttive significativamente maggiore rispetto ai bambini che non gattonano, confermando i risultati di due precedenti studi (Campos et al., 1992; Zunbahlen & Crawley, 1997). Le direttive dei genitori possono avere un effetto diretto sul movimento del bambino e uno indiretto sullo sviluppo linguistico, come hanno argomentato Campos et al. (2000) e Iverson (2010). Quando un bambino che gattona intercetta un oggetto proibito (ad esempio, la presa della corrente) o entra in uno spazio proibito (ad esempio, le scale), i suoi caregivers intervengono verbalmente per distrarlo e controllarne i comportamenti attraverso espressioni verbali che sono spesso connotate non solo sul piano dei contenuti ("Fermati! Sulle scale no" oppure "Non toccare la presa!") ma anche sul piano prosodico, con un volume che si alza e un'inflessione della voce che punta a sottolineare l'autorità di chi la usa. I bambini esposti a direttive pronunciate in questo modo, rispondono solitamente orientando lo sguardo verso il proprio caregiver per cogliere il messaggio comunicativo lanciato dall'adulto. Inizia un momento di attenzione condivisa che, nel tempo, può facilitare la comprensione di alcuni gesti comunicativi come l'indicare o il *matching* tra referente ed etichetta verbale (Moore, 1999). Il gattonamento determina pertanto un cambiamento negli input verbali offerti dai caregiver ai bambini, che a sua volta, può innescare effetti a cascata su alcune abilità di base fondamentali nello sviluppo del linguaggio come la capacità di comprendere input comunicativi diretti verso referenti al di fuori del loro campo visivo. Un ulteriore risultato di questo studio riguarda i feedback positivi offerti dai genitori, che risultano essere maggiori nei confronti dei bambini che ancora non gattonano. Una possibile interpretazione è che con i bambini che a 8 mesi ancora non gattonano i momenti di interazione connotati da vicinanza siano maggior rispetto a quelli connotati da lontananza, che incrementano con l’avvio della locomozione autonoma quando il bambino inizia di fatto ad allontanarsi autonomamente dai suoi *caregivers*. La condizione di vicinanza/lontananza potrebbe portare i genitori ad una maggiore attenzione rispetto al fare/non fare del bambino e di conseguenza ad utilizzare feedback in risposta ad azioni (anche “micro”) messe in campo dal bambino. Un'altra possibile interpretazione è che i genitori dei bambini meno competenti sul piano motorio cerchino di stimolare e sostenere nel bambino un avanzamento nella competenza attraverso il meccanismo del rinforzo, che però non agisce in maniera specifica, ma piuttosto in maniera diffusa. Risulta pertanto difficile interpretare un effetto dei feedback positivi sul solo sviluppo linguistico.

Lo studio ha infine evidenziato come la locomozione autonoma (a 8 e 12 mesi) possa concorrere assieme ad altri fattori individuali a sociali a sostenere lo sviluppo di alcune abilità linguistiche nel breve e nel medio termine. Nel dettaglio, alcuni modelli di regressione hanno mostrato che a 8 mesi l'avvio del gattonamento, combinato con fattori quali il genere del bambino e la qualità dell’input linguistico dei genitori (richieste verbali che promuovono acquisizione del linguaggio) ha un effetto sull'ampiezza del repertorio di comportamenti comunicativi misurato alla stessa età; inoltre, controllando le abilità linguistiche del bambino, l'avvio del cammino a 12 mesi combinato con lo *scaffolding* linguistico fornito dai genitori predice il vocabolario recettivo a 16 mesi. Anche questi risultati supportano le interpretazioni esposte poco sopra inerenti le più ampie opportunità di interagire attivamente con l'ambiente offerte ai bambini dall’acquisizione di abilità motorie, ma evidenziano come lo sviluppo delle abilità linguistiche sia il risultato di diversi fattori tra cui, in una logica partecipatoria, le competenze motorie possono offrire un contributo.

Le relazioni tra sviluppo motorio e sviluppo linguistico a cavallo tra il secondo e il terzo anno d'età: il potenziale contributo delle capacità coordinative

Lo studio, oltre a confermare precedenti risultati inerenti la relazione predittiva tra competenza motoria globale e abilità linguistiche a 24 mesi (Alcock

& Krawczyk, 2010), ha offerto alcune originali evidenze rispetto alla specificità della relazione movimento-linguaggio in una fascia d'età poco indagata in letteratura (quella a cavallo tra il secondo e il terzo anno di vita). La coordinazione dinamica generale misurata a 18 e a 24 mesi risulta essere in relazione con diverse abilità linguistiche sia a 24 che a 30 mesi. Un'alta *performance* in questa capacità coordinativa rivela che i bambini hanno già acquisito i principali *milestones* grosso-motori come camminare o salire le scale. Questi stessi bambini non hanno più la necessità di "pensare a camminare", ma possono contemporaneamente camminare e prestare attenzione agli oggetti e a ciò che accade attorno a loro e pertanto spostare l'attenzione dal movimento ad altri apprendimenti. Questo processo è in linea con quanto evidenziato da alcuni studi sulla riallocazione delle risorse socio-cognitive nei momenti di transizione (Berger et al., 2017; Geva & Orr, 016), che hanno mostrato come le risorse socio-cognitive si spostino dal dominio socio-linguistico a quello motorio durante alcuni momenti cruciali dello sviluppo motorio, quali l'acquisizione del gattonamento e del cammino. I nostri risultati mostrano inoltre che la coordinazione dinamica generale in combinazione con una capacità coordinativa fine, la coordinazione bilaterale, misurata a 24 mesi predice il vocabolario spaziale misurato a 30 mesi; per contro, non abbiamo trovato nessuna relazione significativa tra le capacità coordinative fini misurate a 18 mesi e le abilità linguistiche misurate a 24 mesi. Questi risultati confermano l'ipotesi già espressa nella Discussione della revisione della letteratura, che il potenziale impatto delle capacità fino-motorie sullo sviluppo linguistico possa essere tardivo, come dimostrano anche gli studi che hanno considerato le capacità di presa e manipolazione nei primi mesi di vita, non trovando nessuna relazione significativa con le abilità linguistiche misurate successivamente (Libertus & Klaus, 2016). Infine da evidenziare il risultato che riguarda il vocabolario spaziale, che offre ulteriori conferme a supporto della specificità della relazione tra movimento e linguaggio. A 18 mesi, la coordinazione dinamica generale da sola predice la produzione di predicati, e a 24 mesi, in combinata con la coordinazione bilaterale, predice la comprensione del vocabolario spaziale. Quando i bambini si muovono nell'ambiente, raccolgono informazioni sullo spazio e sulle proprie azioni in quel processo di percezione-azione che abbiamo descritto nell'Introduzione. Pertanto i bambini possono fare esperienza diretta del concetto di "altezza" salendo le scale o di "sotto" partendo dal loro stare sotto ad un tavolo mentre attendono di essere trovati dai genitori. Queste esperienze dirette di un concetto possono facilitare il successivo abbinamento tra referente ed etichetta verbale, soprattutto in relazione ai contenuti più connotati sul piano motorio.

Apporti originali del progetto di ricerca

Il progetto di ricerca offre alcuni apporti originali all'indagine sulle relazioni tra sviluppo motorio e sviluppo linguistico nei primi anni di vita del bambino. Innanzittutto è uno dei primi studi che ha indagato tale relazione in un campione di bambini italiani con sviluppo tipico. Alcuni precedenti studi si sono focalizzati su popolazioni atipiche (Zuccarini et al., 2017, 2018); uno ha considerato bambini con sviluppo tipico, ma utilizzando misure globali di sviluppo motorio invece che specifiche (Longobardi et al., 2014). La specificità delle misure motorie utilizzate rappresenta un secondo apporto originale ed è stata declinata seguendo due direttrici: una relativa agli schemi motori (*milestones*) e una alle capacità coordinative. La prima ci ha orientato a focalizzare l'attenzione sul gattonamento, come prima forma di locomozione autonoma, fino ad ora poco indagato in letteratura in relazione allo sviluppo linguistico (la maggior parte delle evidenze riguardano il cammino). La seconda ci ha portato a spostare l'attenzione dai milestones alle capacità coordinative per poter garantire la specificità della misurazione dello sviluppo motorio in bambini più grandi; abbiamo considerato il periodo a cavallo tra il secondo e il terzo anno di vita (anch'esso poco indagato in letteratura) caratterizzato sul piano motorio dal fatto che i principali milestones sono già stati acquisiti e il bambino si avvia a lavorare su una loro esecuzione coordinata ed efficiente, garantita proprio dalle capacità coordinative. Infine, l'approccio multimetodo con l'utilizzo combinato di questionari, strumenti di valutazione standardizzati e di osservazioni ha inoltre permesso un'indagine in grado di tenere in considerazione sia fattori individuali che sociali e il loro potenziale effetto combinato sullo sviluppo linguistico del bambino.

Limiti

Questo progetto ha numerosi limiti che abbiamo evidenziato in relazione ai singoli studi; sintetizziamo qui i due principali.

Il primo riguarda i campioni coinvolti in entrambi gli studi, sia per quanto riguarda la numerosità, sia per quanto riguarda le caratteristiche socio-demografiche. Nonostante sia presente una certa variabilità, si tratta di famiglie che presentano un livello medio-alto di scolarizzazione e un reddito che può garantire al bambino un adeguato contesto di crescita. Inoltre, la maggior parte dei partecipanti risiede in zone d'Italia (province di Trento e Bolzano) che offrono una migliore qualità della vita rispetto ad altre zone, e mostrano una particolare attenzione ad alcuni aspetti dell'esperienza quotidiana dei bambini, quali lo sviluppo motorio (si pensi alla presenza di parchi gioco attrezzati).

Il secondo limite è legato agli strumenti utilizzati per la raccolta dei dati relativi alle competenze motorie e linguistiche nel primo studio, entrambi questionari compilati dai genitori. E' vero che questa loro caratteristica ha di fatto consentito al progetto di essere realizzato (a causa del Covid non sarebbe stato possibile raccogliere diversamente i dati). D'altro canto, è reale il rischio legato alla sotto-stima o sovra-stima delle competenze dei bambini da parte dei genitori, che nella maggior parte dei casi non hanno conoscenze specifiche rispetto alle competenze indagate. L'approccio multimetodo che ha incluso la realizzazione di videoregistrazioni dell'interazione del bambino con il/i genitore/i ci ha tuttavia consentito di mettere in campo un sistema di verifica seguito, solo in pochi casi, da una revisione della valutazione delle competenze motorie.

Sviluppi Futuri e Questioni Aperte

I risultati degli studi di questo progetto di ricerca approfondiscono l'attuale conoscenza della relazione tra sviluppo motorio e sviluppo linguistico, ma numerosi rimangono gli aspetti che necessitano di ulteriori indagini. Ne evidenziamo tre, che riteniamo particolarmente importanti; uno riguarda potenziali piste di approfondimento e due rimandano a questioni aperte.

Il primo aspetto inerisce la misurazione delle competenze motorie. Abbiamo già evidenziato l'importanza di spostare l'attenzione da misure globali a misure specifiche di sviluppo motorio. Infatti, i risultati derivanti da una misura globale possono supportare o meno l'esistenza di una relazione tra dominio motorio e dominio linguistico, ma senza contribuire alla comprensione di come una competenza motoria (e soprattutto le conseguenze derivanti dall'acquisizione di quella competenza motoria nella quotidianità del bambino e della sua famiglia) possa attivare percorsi a cascata in grado di influenzare anche lo sviluppo linguistico. Declinare la misurazione delle competenze motorie in termini di specificità significa considerare, come abbiamo evidenziato in un precedente paragrafo, sia *milestones* che capacità coordinative a seconda dell'età e della fase di sviluppo che si sta indagando. A questo rigurado, abbiamo già avviato uno studio di carattere metodologico che ci consentirà di dettagliare un sistema di competenze motorie da poter considerare (*milestones* e capacità coordinative, sia grosso- che fino-motorie) derivandole dal questionario utilizzato per la raccolta dati sullo sviluppo motorio del bambino: l'EMQ (*Early Motor Questionnaire*; Libertus & Landa, 2013).

Una prima questione aperta riguarda i molteplici fattori individuali e sociali che possono influenzare lo sviluppo in ambito motorio o linguistico e favorire (o meno) i possibili effetti a cascata che conquiste nello sviluppo motorio possono innescare in altri domini di sviluppo, incluso quello linguistico. In una prospettiva sistemica, come quella che abbiamo assunto per l'impostazione di questo progetto di ricerca, è importante considerare i tanti fattori che possono condizionare o direttamente lo sviluppo motorio o direttamente l'acquisizione del linguaggio o mediare/moderare possibili legami tra i due domini. Come abbiamo anticipato nella sezione Metodo relativa allo Studio 1 del primo studio, sono già stati raccolti dati relativi alle caratteristiche fisiche dell'ambiente casa (dimensioni, presenza/assenza di scale e di giardino) e alle abitudini sia motorie (frequentazione del parco giochi) che linguistiche (lettura condivisa di libri per piccolissimi, conversazioni, utilizzo della voce per cantare e giocare, etc.). Le utilizzeremo per indagare se/come questi fattori possono interagire con lo sviluppo motorio e l'input dei genitori nel favorire (o meno) lo sviluppo linguistico.

Infine, una seconda questione aperta riguarda i meccanismi, processi, interazioni tra fattori che sottendono i potenziali legami tra sviluppo motorio e sviluppo linguistico. I risultati dei nostri studi, come quelli di altri studi, ci dicono che è presente o non è presente una relazione concorrente o longitudinale tra una determinata competenza motoria e una determinata abilità linguistica. Pochi studi suggeriscono che l'acquisizione di una competenza motoria fondamentale (quale ad esempio il cammino) riesca ad attivare nel breve e medio termine un effetto a cascata sulla competenza linguistica, ma si "fermano" (ed è già moltissimo) a dimostrare che l'acquisizione motoria riorganizza i pattern di interazione diadica tra caregiver e bambino, modellando il linguaggio del caregiver nell'interazione (Schneider & Iverson, 2021). Gli ulteriori effetti dei nuovi pattern di interazione diadica e dei cambiamenti di input del caregiver sull'acquisizione del linguaggio sono suggeriti, ma questa è la strada di ricerca più promettente. Dei possibili effetti a cascata di altre acquisizioni motorie si sa ancora relativamente poco. Nello Studio 1 abbiamo iniziato l'esplorazione dell'impatto del crawling nell'interazione del caregiver con il bambino e degli effetti sulle abilità comunicative di quest'ultimo. La continuazione di questa indagine con un campione più esteso e l'adozione di particolari attenzioni metodologiche, così come l'esplorazione dei processi sottesi all'impatto dell'abilità di coordinazione motoria sui pattern di interazione e l'acquisizione di specifiche abilità linguistiche rappresentano le sfide più avvincenti negli sviluppi futuri di questo ambito di ricerca.

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